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A MODEL FOR CALCULATING DISPERSION AND DEPOSITION OF SMALL PARTICLES FROM A LOW LEVEL POINT SOURCE (U)

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Stanley B. Mellsen

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ABSTRACT

micrometers

A mathematical model for estimating concentrations and ground deposition densities from a low level point source of particulates up to 20 µm in diameter has been developed. The model applies K theory to account for vertical dispersion and Gaussian spread to account for lateral dispersion. Results for the limiting case of zero terminal velocity with negligible retention at the ground are compared directly to field experimental data for a source near ground level to establish the validity of using Gaussian lateral dispersion from an elevated source. The vertical dispersion function and lower boundary condition for an existing line source model were applied in the present point source model. Previous comparison to ground deposition densities measured in various field experiments indicate that estimates from the line source model are reasonable, although further experiments would be useful. (Canada)

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LIST OF SYMBOLS

A	constant to account for variations in eddy diffusivity due to atmospheric stability
B	sublayer Stanton number
C (x,z)	total dosage for an instantaneous line source, g s m^{-3}, or steady state concentration from a continuous line source, g m^{-3}
C(x,y,z)	total dosage for an instantaneous point source g s m^{-3}, or steady state concentration from a continuous point source g m^{-3}
D	drop diameter, mm
E	efficiency of retention or capture by the substrate
F(x,z)	vertical flux of diffusing material, g m^{-2} for an instantaneous source and g m^{-2} s^{-1} for a continuous source
h	release height of line source, m
H	upper boundary of the turbulent boundary layer, m

$K(z)$	coefficient of vertical eddy diffusivity at height z, $m^2\ s^{-1}$
$\Delta\ell$	length of the same order as the roughness length of the substrate z_0, m.
p	exponent in power law wind velocity profile
P_a	mean transport velocity between the turbulent atmosphere and the rough surface, $m\ s^{-1}$
P_s	apparent mean transport velocity through the horizontal plane at z=0 $m\ s^{-1}$
Q	source strength, $g\ m^{-1}$ for an instantaneous line source and $g\ m^{-1}\ s^{-1}$ for a continuous line source
Q_p	source strength g for an instantaneous point source and $g\ s^{-1}$ for a continuous point source
q	terminal velocity of particles, $m\ s^{-1}$
$R(z)$	vertical diffusive resistance of the atmosphere at height z, $m^{-1}\ s$
S	total surface area of the roughness element per unit horizontal area

$u(z)$	mean horizontal wind speed in x direction at height z, m s^{-1}
x	horizontal down wind distance, m
y	horizontal crosswind distance, m
z	vertical height above ground, m
σ_y, σ_z	crosswind and vertical plume standard deviations, m
ω	contamination density, g m^{-2} from an instantaneous source and g m^{-2} s^{-1} from a continuous line source

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A MODEL FOR CALCULATING DISPERSION AND DEPOSITION OF SMALL PARTICLES FROM A LOW LEVEL POINT SOURCE

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INTRODUCTION

1. A mathematical model which includes the effect of atmospheric diffusion on dispersion and settling was developed at the Defence Research Establishment Suffield [1,2]. Calculation of airborne concentrations and mass deposition densities downwind of an elevated line source of non-evaporating spray or solid particles can be calculated from this model. Knowledge of aerial concentration and mass deposition density from a low level point source is also useful in applications related to chemical and biological defence. Therefore, the line source model has been extended to calculate these quantities from a point source. The purpose of this report is to describe this point source model and to provide some comparision to previously available data from field experiments of other workers.

OUTLINE OF THE LINE SOURCE MODEL

2. The differential equation, boundary conditions and functional forms for the wind velocity profile, transport velocity to the rough surface, and particle terminal velocity were stated previously [1,2], but are provided for convenience. The details of the solutions are shown elsewhere [1,2].

Differential Equation

3. The equation used to describe turbulent diffusion of monodisperse particulate matter in the atmosphere from a uniform infinite crosswind line source is:

$$u(z)\ \partial C(x,z)/\partial x = \partial/\partial z\{K(z)\partial C(x,z)/\partial z\} + q\partial C(x,z)/\partial z \qquad (1)$$

where C = total dosage for an instantaneous source
= steady state concentration from a continuous source
x = horizontal downwind distance
z = vertical height above ground
K(z) = the coefficient of eddy diffusivity at z
u(z) = mean horizontal wind speed at z
q = terminal velocity of the particles

This equation and its boundary conditions have been discussed by Calder [3], who indicated the problems in stating the lower boundary condition with regard to the transport of material through this boundary of the turbulent atmosphere to the ground or substrate. Monaghan and McPherson [4] have proposed an equation for the transport of vapour to rough natural surfaces based on work by Chamberlain [5] which relates the trans-

port of vapour to the substrate in terms of windspeed at 2 m above ground, the roughness and specific area of the substrate, and an absorption velocity, characteristic of the vapour, into the roughness elements of the substrate. This equation has been modified to include the terminal velocity of particulate matter and its retention by the roughness elements. As for the case of vapour diffusion, it is assumed that the turbulent airstream is bounded by the non-turbulent atmosphere which acts as a lid to vertical diffusion.

Boundary Conditions

4. The vertical flux $F(x,z)$ of diffusing material is given by:

$$F(x,z) = -\{K(z)\partial C(x,z)/\partial z + qC\}, \tag{2}$$

where F is positive in the direction of increasing z, and therefore,

$$u(z)\partial C(x,z)/\partial x = -\partial F(x,z)/\partial z \tag{3}$$

At the upper boundary $z = H$,

$$\lim_{z \to H} F = o \tag{4}$$

At the lower boundary,

$$\lim_{z \to o} \{-F(x,z)\} = ES(P_a + q/S) \lim_{z \to o} C(x,z), \tag{5a}$$

$$= E(P_s + q) \lim_{z \to o} C(x,z), \qquad (5b)$$

where E is the efficiency of retention (or capture), S is the total surface area of the roughness elements per unit horizontal area, P_a is the mean transport velocity of material between the turbulent atmosphere and the rough surface. P_s is the apparent mean transport velocity through the horizontal plane at z = o.

The upper and lower boundary conditions are given by:

$$\lim_{z \to H} \{K(z)\, \partial C(x,z)/\partial z + qC(x,z)\} = o \qquad (6)$$

and

$$\lim_{z \to o} \{K(z)\, \partial C(x,z)/\partial z + qC(x,z)\} = ES(P_a + q/S) \lim_{z \to o} C(x,z) \qquad (7a)$$

$$= E(P_s + q) \lim_{z \to o} C(x,z) \qquad (7b)$$

Boundary Condition for a Material Source

5. Assuming a line source, then from mass balance considerations in equation (1)

$$\lim_{x \to o} C(x,z) = Q\delta(x-h)/u(h) \qquad (8)$$

where Q is source strength (mass per unit length for an instantaneous line source), h is release height and δ is the Dirac delta function.

Functional Forms of $u(z)$, P_s, q

6. a. A number of functional forms for $u(z)$ have been proposed. In this model a power-law form is used:

$$u(z) = u(2) \{(z + \Delta\ell)/(2 + \Delta\ell)\}^p \tag{9}$$

where z is in metres, p is a function of atmospheric stability and $\Delta\ell$ is a length of the same order as the roughness length z_o.
K(z) is given by:

$$K(z) = A(z + \Delta\ell)u(2) \tag{10}$$

where A is a constant dependent upon atmospheric stability. Monaghan and McPherson [4] have published values of A, $\Delta\ell$ and p for stable to slightly unstable conditions by fitting their vapour diffusion model to field data and Pasquill's data on vapour cloud height. P_a is related to the reciprocal of the sublayer Stanton number B by the approximate equation:

$$P_a = u_*/B^{-1}S \tag{11}$$

Since u_* is approximately a factor of 10 less than u(2)

$$P_a = 0.1u(2)/B^{-1}S \qquad (12)$$

Chamberlain (1966) suggests values of B^{-1} between 5 and 8 for grass with S equal to approximately 2. Hence the equation:

$$P_a = 0.01\ u(2) \qquad (13)$$

is used for all stability categories.

b. Thom [6] quotes values of B^{-1} for a variety of rough surfaces which range from 5 for grassland to 2 for a pine forest. Thus, if P_a is assumed to be the same for all these surfaces, S varies from 2 for grassland to 5 for the forest. Suggested values of A, $\Delta\ell$, p, u(2) and H are given in Table I for various Pasquill atmospheric stability categories.

c. Assuming the particulate is a liquid of approximately unit specific gravity and diameter D, Best's equation [7] for terminal velocity can be used:

$$q = A\{1 - \exp(-BD^{c})\}; \qquad (14)$$
$$q = 9.43\ \{1-\exp[-(D/1.77)^{1.147}]\}$$
for $0.3 \le D \le 6.0$
q is in m $\cdot$ s^{-1} for D in mm.

Below D = 0.3 mm equations for fluid drag on spheres are used.

SOLUTIONS OF EQUATIONS

Numerical Methods

7. The diffusion equations are solved by finite difference methods using a Crank-Nicolson formulation to reduce the difference scheme to a tridiagonal matrix which is inverted by the Gauss elimination method using a digital computer. Errors in discretization are reduced by subdividing the atmosphere vertically into equal increments of diffusive resistance R rather than height, using the relationship

$$R(z) = \int_0^z dz/K(z) \text{ or } dR(z)/dz = 1/K(z). \quad (15)$$

8. This procedure also economizes on computer storage. The equations are solved for C(x,z) and deposition of particulate in the substrate. In the latter case, equation (7) will give rate of deposition for a continuous source or deposition density (mass/unit horizontal area = ω) for an instantaneous source. As stated previously, the details are described elsewhere [1,2].

TABLE I
VALUES OF CONSTANTS

CONSTANTS

STABILITY CATEGORY	A	$\Delta\ell$ / m	p	u(2) / m/s	H / m
C	0.08	0.025	0.2	2-4	1000
D	0.04	0.025	0.23	≥3	500
E	0.03	0.025	0.3	1.5-3	200
F	0.02	0.025	0.5	1.5-2	100

$\Delta\ell$ is given for grassland

POINT SOURCE MODEL

Description and Justification of the Method

10. The extension of the line source model was accomplished by applying Gaussian lateral distribution to the solution calculated from the K theory line source model. The justification for this is that in practical applications the lateral distribution over simple terrain without major obstacles is Gaussian [8]. This applies only to gaseous clouds or particles small enough so that they follow the air movement with negligible slip. Since particle dispersion as well as gas dispersion is considered, sensitivity tests for the effect of particle size on airborne concentrations and mass deposition densities were performed by comparing results for various sizes of particles up to 20 μm diameter. In this way the assumption that particles closely follow the air flow can be verified.

11. Vertical distributions are approximately Gaussian only for some elevated sources, yet it is common practice to assume the distribution from pollutants emitted near the surface is also Gaussian [8]. The Gaussian vertical distribution assumes that the coefficient, K, is independent of height which is not generally realistic. The vertical diffusion coefficient as given by equation (10), with constants A and $\Delta \ell$ given in Table I, is realistic for open prairie terrain without major obstacles [1,2,4].

12. The condition of conservation of mass, called the continuity condition, must be satisfied. As for the line source model, the x direction is downwind, and z vertical. The direction designated by y is horizontal and 90° to the left of the x direction. A different meaning

was used for y in the line source model, but since it does not appear explicitly in this report, it can be used in the conventional manner. The continuity conditions which assume no turning of wind with height are given as follows. For a single continuous line source at right angles to the mean wind direction the continuity condition is (steady conditions)

$$Q_p = \int_{-\infty}^{\infty} C(x,z)\ u(z)\ dz \tag{16}$$

where Q is the source strength in mass per unit length per unit time, C(x,z) is the concentration.

For a single continuous point source the continuity condition is (steady conditions)

$$Q_p = \iint_{-\infty}^{\infty} C(x,y,z)\ u(z) dy\ dz \tag{17}$$

where Q_p is the source strength in units of mass per unit time and C(x,y,z) is the concentration. Equations (16) and (17) must be satisfied for all distances x downwind.

13. Almost all the solutions to equations (16) and (17) are based on the same general forms [8]. Three independent dispersion functions, G(x), H(y) and I(z) that are independent of each other, are assumed. The continuity conditions, equations (16) and (17) can be satisfied by the solutions for the following equations. For the continuous line source

$$C(x,y) = \frac{Q\ I(z)}{u(z)} \tag{18}$$

and for the point source

$$C(x,y,z) = \frac{Q_p\ H(y)\ I(z)}{u(z)} \tag{19}$$

where H and I also depend upon x [8].

14. Solutions (16) and (17) require that the dispersion functions act independently. This is usually the case, to a good approximation [8]. The most serious exception occurs when the wind direction changes with height. In that case H(y) varies with height and therefore also depends on z. Most observations of vapour dispersion indicate that K(z) increases with distance from the source [8]. The reason is that in the atmosphere there are eddies of all sizes. As the plume grows, larger eddies become relatively more important, so K(z) must be allowed to increase with travel time or distance. If the source is at or near the surface, the centre of gravity of the plume will rise with downwind distance. Therefore, since K(z) varies directly with height as shown in equations (10), the effective value K(z) will increase with distance, even if it is assumed to vary with height only, and the solutions of (1) for q = 0, which represent dispersion of a gaseous cloud, are quite realistic [8]. For particulate dispersion, the terminal velocity is greater than zero, which corresponds to q > 0 in equation 1. Therefore the height of the centre of gravity of the plume rises less with downwind distance. In the atmosphere, the characteristic vertical dimension of eddies is of the same order as the distance above the ground [9]. Therefore the effective value of K(z) can be expected to increase less with down wind distance for particulates with considerable terminal velocity than for gases. Again the physics is compatible with equation (10) in which K(z) is proportional to height.

15. Assuming then that I(z) is given by K theory and H(y) is a

Gaussian distribution, the line source solution outlined in paragraphs 3 to 8 with $q = 0$ in equation (10) can be applied to calculate concentrations downwind of a point source as follows. Substituting equation (18) into equation (19) gives

$$C(x,y,z) = \frac{Q_p\, C(x,z)\, H(y)}{Q} \tag{20}$$

where H(y) is given by the basic form of the Gaussian lateral distribution as follows

$$H(y) = \frac{1}{\sqrt{2\pi}\,\sigma_y} \exp\left(\frac{-y^2}{2\sigma_y}\right) \tag{21}$$

The term σ_y is the standard deviation of y. Actual values of σ_y are given by the numerical expressions developed by Briggs [8,10,11] who revised the Pasquill-Gifford diagrams developed from observations over smooth terrain. These are shown in Table II. The plume width is approximately 4 σ_y as 95% of the dispersed material is located within the 2 σ_y to each side of the centre of the distribution.

TABLE II

FORMULAS FOR $\sigma_y(x)$ AND $\sigma_z(x)$ ($10^2 < x < 10^4$ m)

Pasquill Type	σ_y(m)	σ_z (m)
	Open-Country Conditions	
A	$0.22x(1+0.0001x)^{-\frac{1}{2}}$	$0.20x$
B	$0.16x(1+0.0001x)^{-\frac{1}{2}}$	$0.12x$
C	$0.11x(1+0.0001x)^{-\frac{1}{2}}$	$0.08x(1+0.0002x)^{-\frac{1}{2}}$
D	$0.08x(1+0.0001x)^{-\frac{1}{2}}$	$0.06x(1+0.0015x)^{-\frac{1}{2}}$
E	$0.06x(1+0.0001x)^{-\frac{1}{2}}$	$0.03x(1+0.0003x)^{-1}$
F	$0.04x(1+0.0004x)^{-\frac{1}{2}}$	$0.016x(1+0.0003x)^{-1}$
	Urban Conditions	
A-B	$0.32x(1+0.0004x)^{-\frac{1}{2}}$	$0.24x(1+0.001x)^{\frac{1}{2}}$
C	$0.22x(1+0.0004x)^{-\frac{1}{2}}$	$0.20x$
D	$0.16x(1+0.0004x)^{-\frac{1}{2}}$	$0.14x(1+0.0003x)^{-\frac{1}{2}}$
E-F	$0.11x(1+0.0004x)^{-\frac{1}{2}}$	$0.08x(1+0.00015x)^{-\frac{1}{2}}$

Gaussian lateral spread is a good approximation for gaseous clouds, but there is no evidence that it is suitable for particulate clouds with considerable terminal velocity. However, the concentrations calculated for a gaseous cloud can be shown to be close to those for particles with diameters up to 20 μm, which is a size range of interest in practical applications. This is accomplished by comparing concentrations and mass deposition densities calculated for various particle sizes with the line source model. Calculated results, provided later, will show that the differences are small enough so that practical estimates can also be made from the point source model. The mass desposition density for a particle is not necessarily the same as for a gas, but this can be accounted for independently of lateral spread by providing the appropriate retention factor, E, in the lower boundary condition given by equations (7a) and (7b). A non-reactive gas such as argon or helium is not absorbed at all by dry deposition, but once a particle encounters a surface it is considered to have been absorbed [12]. Here E=0 for the non-reactive gas and E=1 for the particle.

CALCULATED RESULTS AND COMPARISON TO EXPERIMENT

16. In this section calculated results are shown from the K theory line source model and the point source model using K theory for the vertical dispersion function and Gaussian distribution for the lateral spread. The results for both types of sources are compared, to a set of values based on carefully constructed diffusion experiments at Porton, England in the 1930's under O.G. Sutton [8,13]. Also the ground level concentration along the wind direction from a gaseous point source with no retention is compared to the results calculated using Gaussian distributions both horizontally and vertically.

17. The line source model "DIFF", was applied using a Fortran computer program [1] on the DRES Honeywell CP-6 system. The point source model "DIFFP" was applied in a similar way. The program, which was developed by modifying the one for the line source, is described in Appendix A. The ground level concentrations using only Gaussian dispersion was calculated from the following equation [8,11]

$$C(x,o,o) = \frac{Q_p}{\pi\sigma_y\sigma_z u(\bar{h})} \exp \frac{-h^2}{2\sigma_z{}^2} \tag{22}$$

Equation (22) is used with the dispersion functions, σ_y and σ_z, given in Table II. These dispersion functions were originally intended for use in estimating ground level concentrations from elevated stack sources [11] and have been developed over many years with industrial applications in mind.

18. The set of values, based on the Porton experiments [13], are repeated for convenience as follows:

a. Experimental Data for Adiabatic Gradient Conditions
The following data are the mean results of many trials with both smoke and gas clouds over level grass land. No difference could be detected between the rates of diffusion of gases and smokes.

(1) The concentration at any point in a continuously generated cloud is directly proportional to the strength of the source, provided that the source itself does not materially interfere with the natural air flow (e.g. by producing intense local convection currents).

(2) For a given strength of source the mean concentration at any point in a continuously generated cloud is approximately inversely proportional to the mean wind speed measured at a fixed height.

(3) The time-mean width of the cloud from a continuous point source measured at ground level, is about 35 m at 100 m downwind of the source and shows only very small variations with the mean wind speed.

(4) The time-mean height of the cloud from an infinite crosswind continuous line source is about 10 m at 100 m downwind of the source and showns only very small variations with wind speed.

(5) The central (peak) mean concentration from a continuous point source decreases with distance downwind, x, according to the law

$$\text{concentration} \propto x^{-1.76}$$

(6) The peak (i.e. ground level) mean concentration from an infinite crosswind continuous line source decreases with distance downwind, x, according to the law

$$\text{concentration} \propto x^{-0.9}$$

(7) The absolute values of the peak mean concentrations at 100 m downwind are as follows:

Type of Source	Strength	Mean Wind at 2 m Height	Peak Concentration
Continuous Point	1 g sec^{-1}	5 m sec^{-1}	2 mg m^{-3}
Continuous infinite line (across wind)	1 g sec^{-1} m^{-1}	5 m sec^{-1}	35 mg m^{-3}

The above data constitutes a standard set of values to which any theory of atmospheric diffusion must conform. It is unfortunate that as yet no corresponding set has been published for non-adiabatic temperature gradients, but it should be emphasized that the general unsteadiness and erratic behaviour of the light winds which are associated with both large lapse rates and large inversions make the experimental study of atmospheric diffusion in these conditions a matter of considerable difficulty.

b. Width and Height of Clouds

The width of a cloud from a continuous point source is the distance between points on the skirts of the crosswind concentration curve at which the concentrations is a fixed fraction, normally one-tenth, of the peak value. Similarly, the height of the cloud is defined as the vertical distance from the ground to the point at which the concentration has fallen to one-tenth of the value on the ground.

19. Downwind concentrations from a line source at 1 m height calculated from the DRES K theory model and from Sutton's mean field trial data are shown in Figure 1. The wind speed at 2 m height is 5 m s^{-1} in neutral atmospheric stability. The terminal velocity, q, was set to zero in equations (1) to simulate a gaseous cloud in the mathematical model. The field trial results were obtained from the peak mean concentration at 100 m and the law for decrease of concentration with downwind distance. Similar results for a point source are shown in Figure 2. Calculated results are also shown for various point source release heights in Figure 3 from the present K theory model with Gaussian lateral spread, and in Figure 4 from Gaussian dispersion given by equation (22). Concentrations 100 m downwind of a line source at 1 m height are shown as functions of height for various retention efficiencies in Figures 5 and 6, for comparison to Sutton's cloud height data. Similar results are shown for a point source for use in practical applications in Figures 7 and 8.

20. The effect of particle size on concentration and ground deposition density from a line source is shown in Figures 9, 10 and 11. Concentrations shown start at 30 m downwind, but one should note that less reliability is expected at short distances than at distances greater than 100 m from the source. The effect of fluctuations have not yet smoothed out, and concentrations vary rapidly with distance at short distances. Figures 9, 10 and 11 compare calculated results for 20 μm diameter particles to particles of less than 1 μm diameter. The terminal velocity of the the 20 μm particle was calculated using equations for fluid drag on spheres [14]. The velocity which was obtained assuming unit specific gravity was 0.01216 m s^{-1}. The terminal velocity of particles less than 1 μ diameter was assumed to be zero. The downwind concentrations are shown in Figure 9 for two atmospheric stability categories, D and F and the ground deposition densities are shown in Figure 10 for stability D and Figure 11 for stability F.

21. As mentioned previously, particles small enough so that their terminal velocity is negligible and which therefore follow the air flow will still not produce the same downwind concentrations as nonreacting gaseous clouds. The reason is that they are affected by the ground surface in different ways. Particles are assumed to have a retention efficiency, E, of 1 and nonreactive gaseous clouds have a retention efficiency of 0. The effect of various retention efficiencies on downwind concentration from a point source is shown in Figure 12. Peak downwind concentrations from a low level point source of particles which follow the air flow are shown in Figure 13 for four atmospheric stability categories. Similarily, peak ground contamination densities are shown in Figure 14.

22. Downwind concentrations from a low level point source of 5 μm and 20 μm diameter particles are shown for four atmospheric stability categories in Figures 15 and 16, respectively. Ground deposition densities for these two particle sizes are shown in Figures 17 to 20. The calculations were performed for particles of unit specific gravity using the point source K theory model with Gaussian lateral spread.

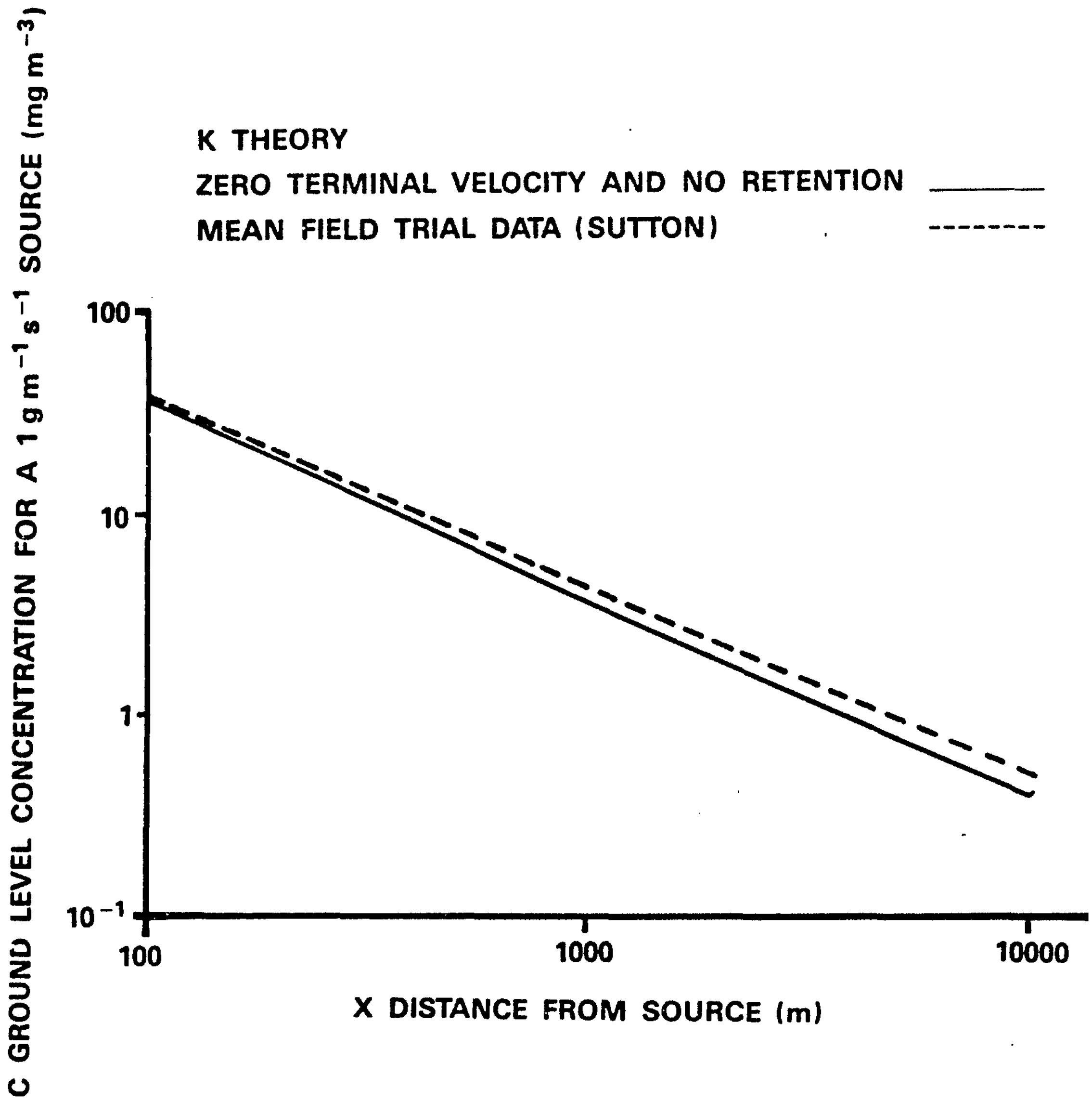


Figure 1

DOWNWIND CONCENTRATIONS FROM A LINE SOURCE AT 1 m HEIGHT IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

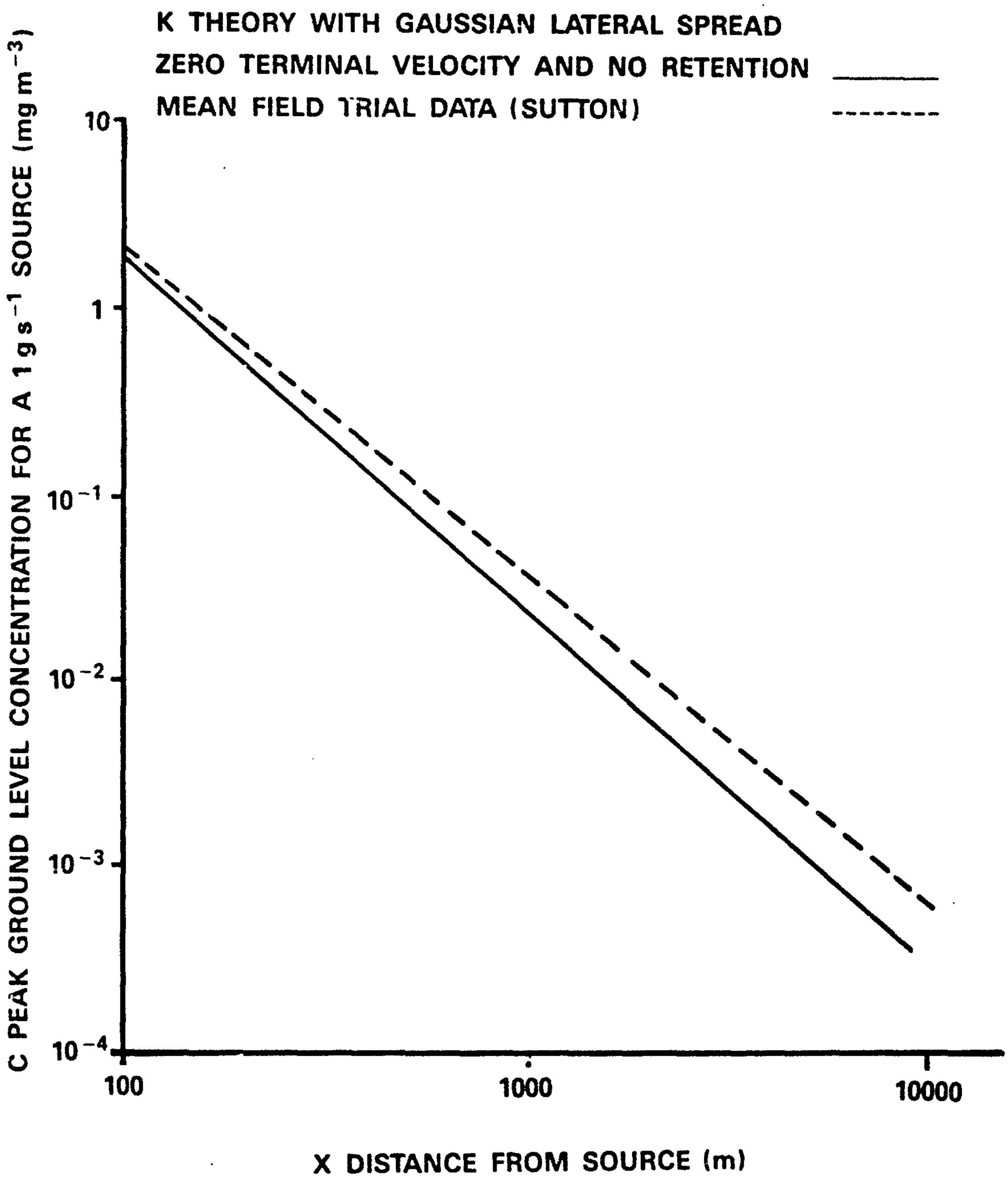


Figure 2

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT 1 m HEIGHT IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

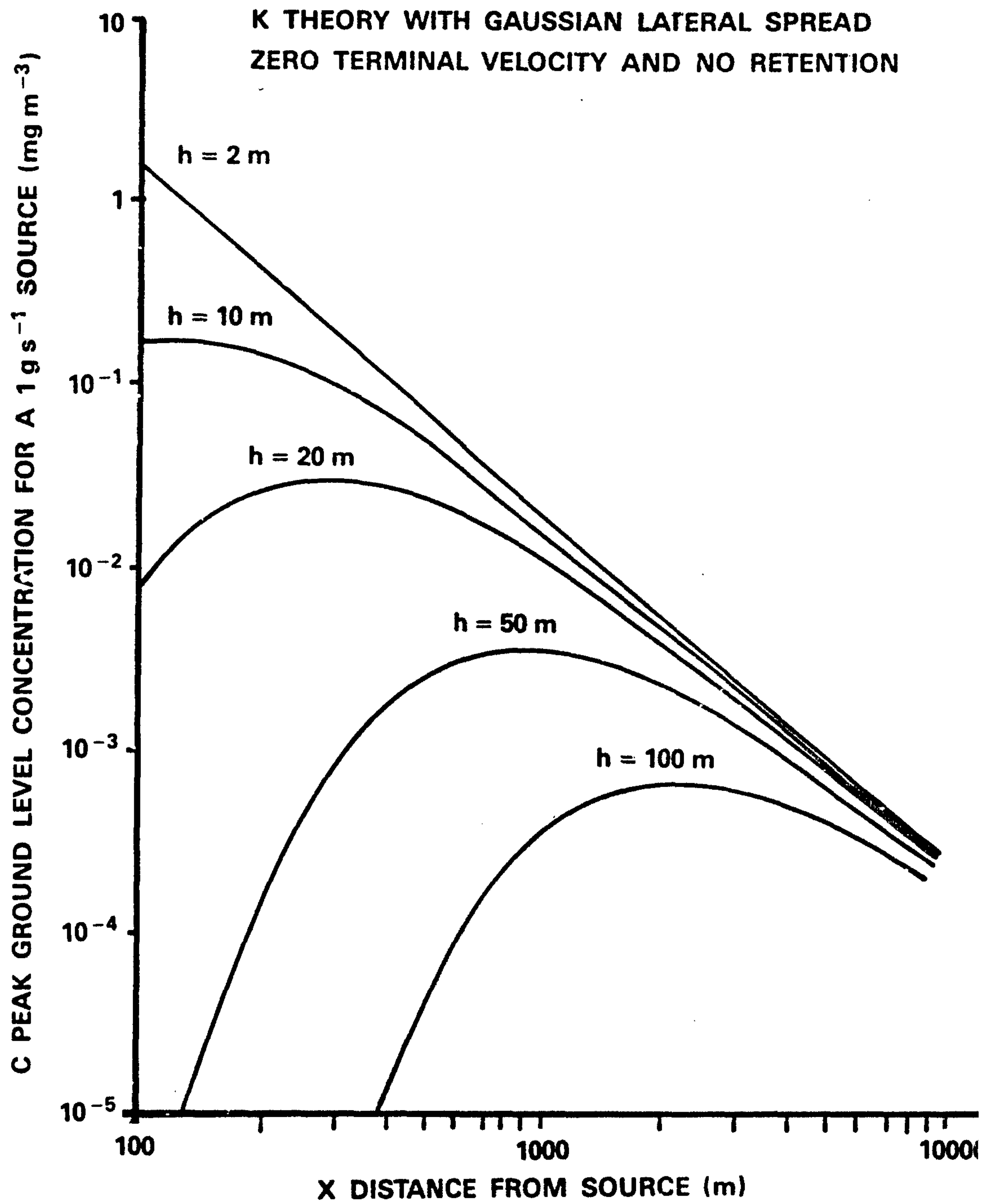


Figure 3

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT VARIOUS HEIGHTS IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

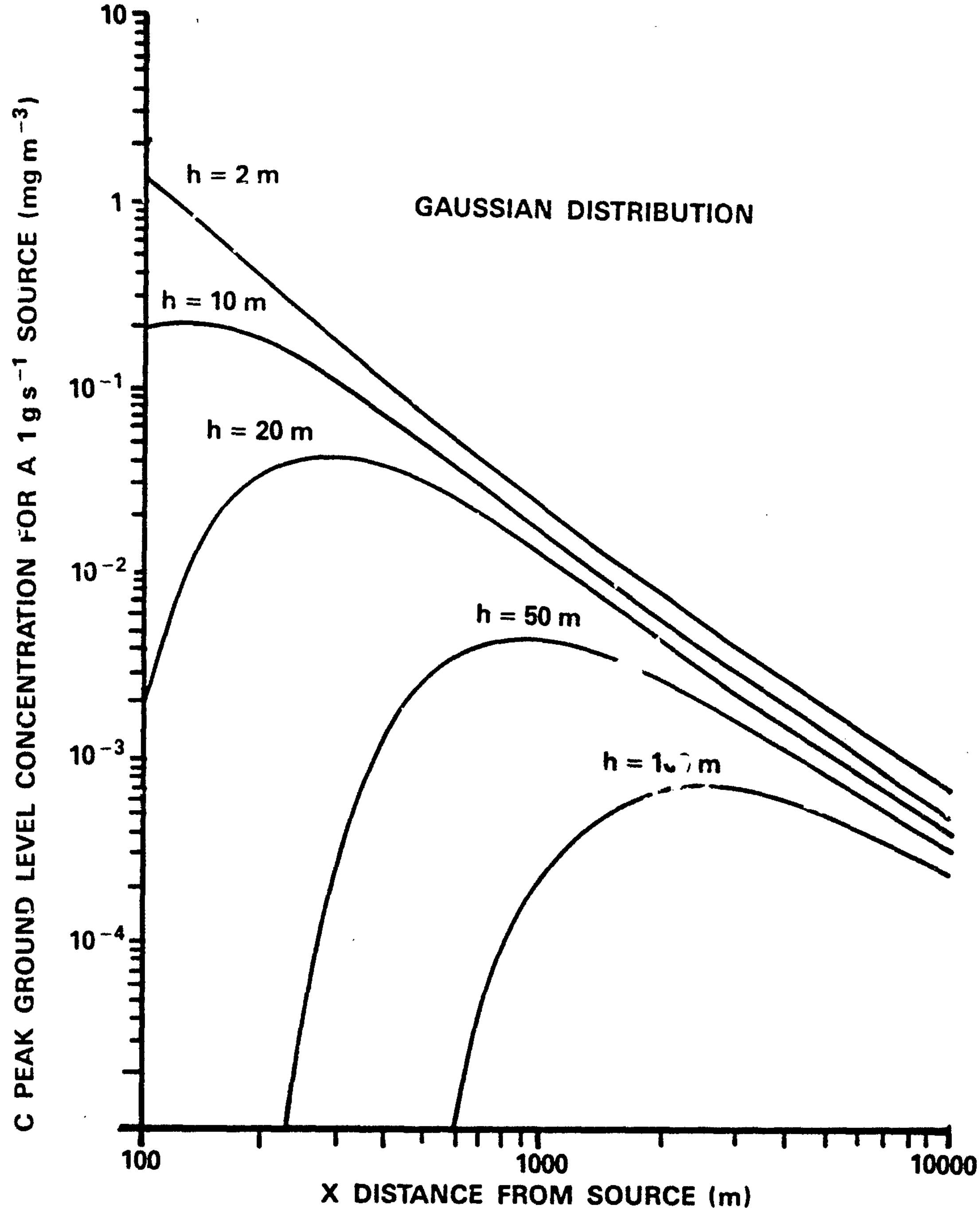


Figure 4

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT VARIOUS HEIGHTS IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

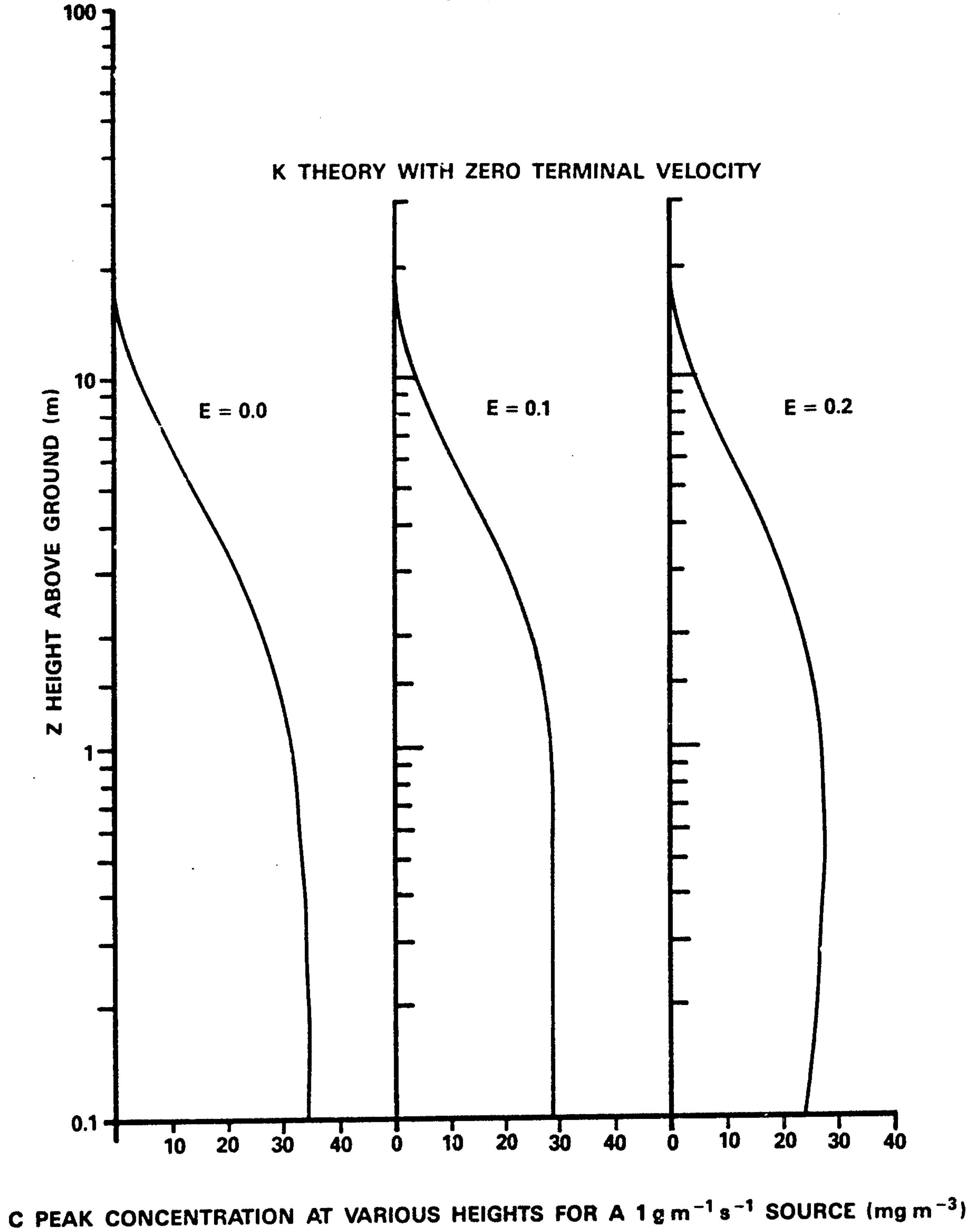


Figure 5

CONCENTRATIONS 100 m DOWNWIND OF A LINE SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

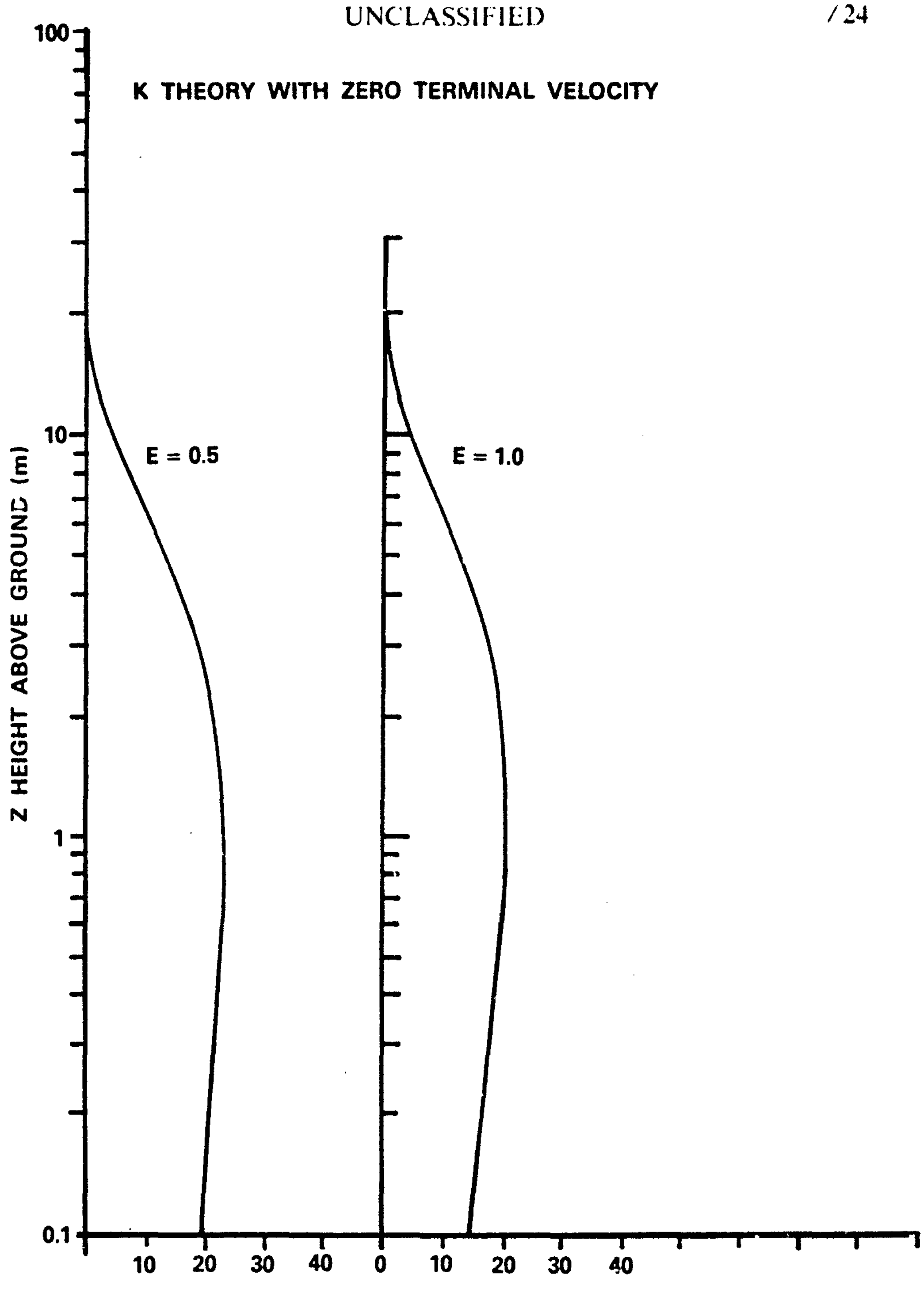
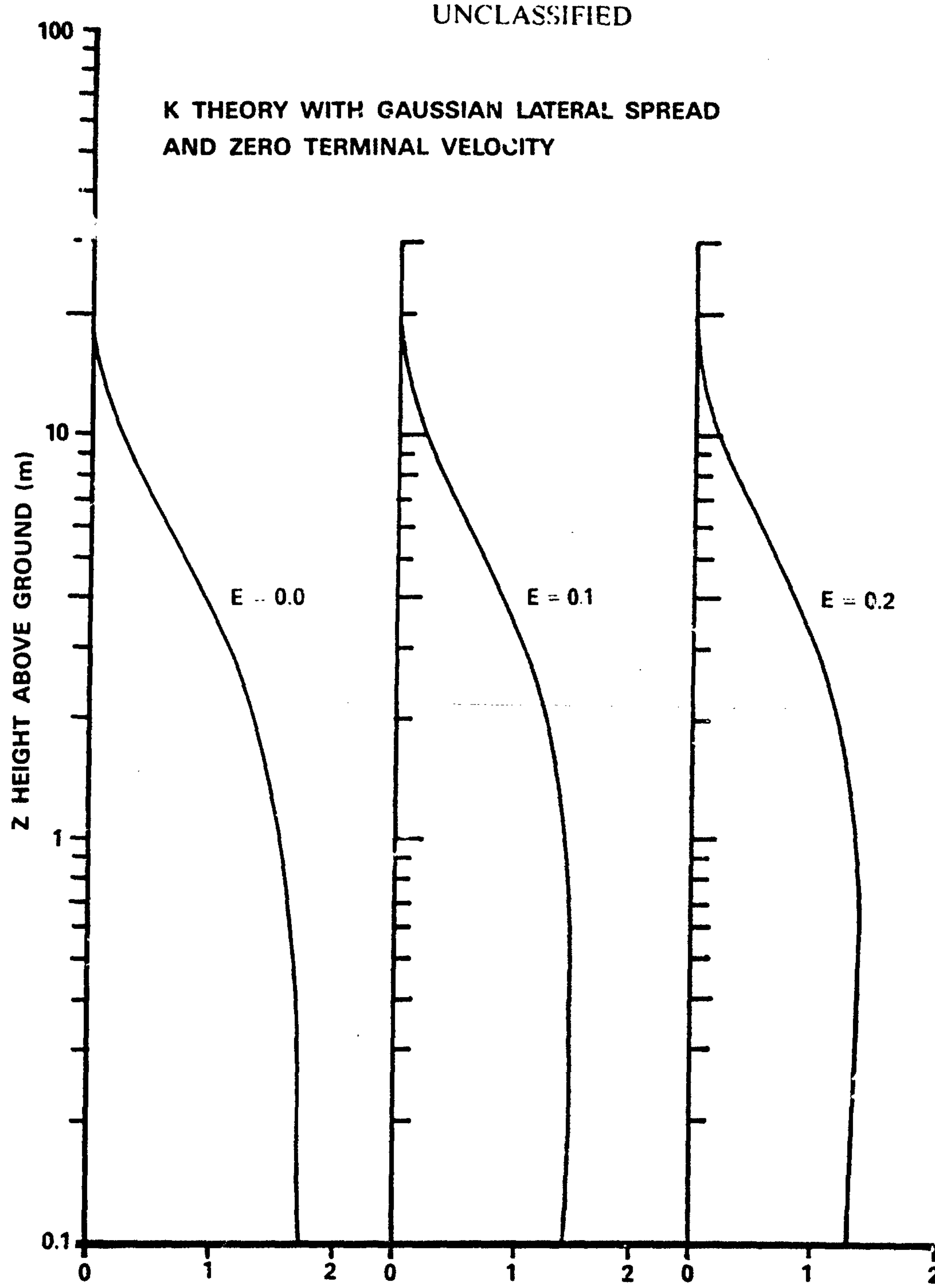


Figure 6

CONCENTRATIONS 100 m DOWNWIND OF A LINE SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}



C PEAK CONCENTRATION AT VARIOUS HEIGHTS FOR A 1 g s^{-1} SOURCE (mg m^{-3})

Figure 7

PEAK CONCENTRATIONS 100 m DOWNWIND OF A POINT SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

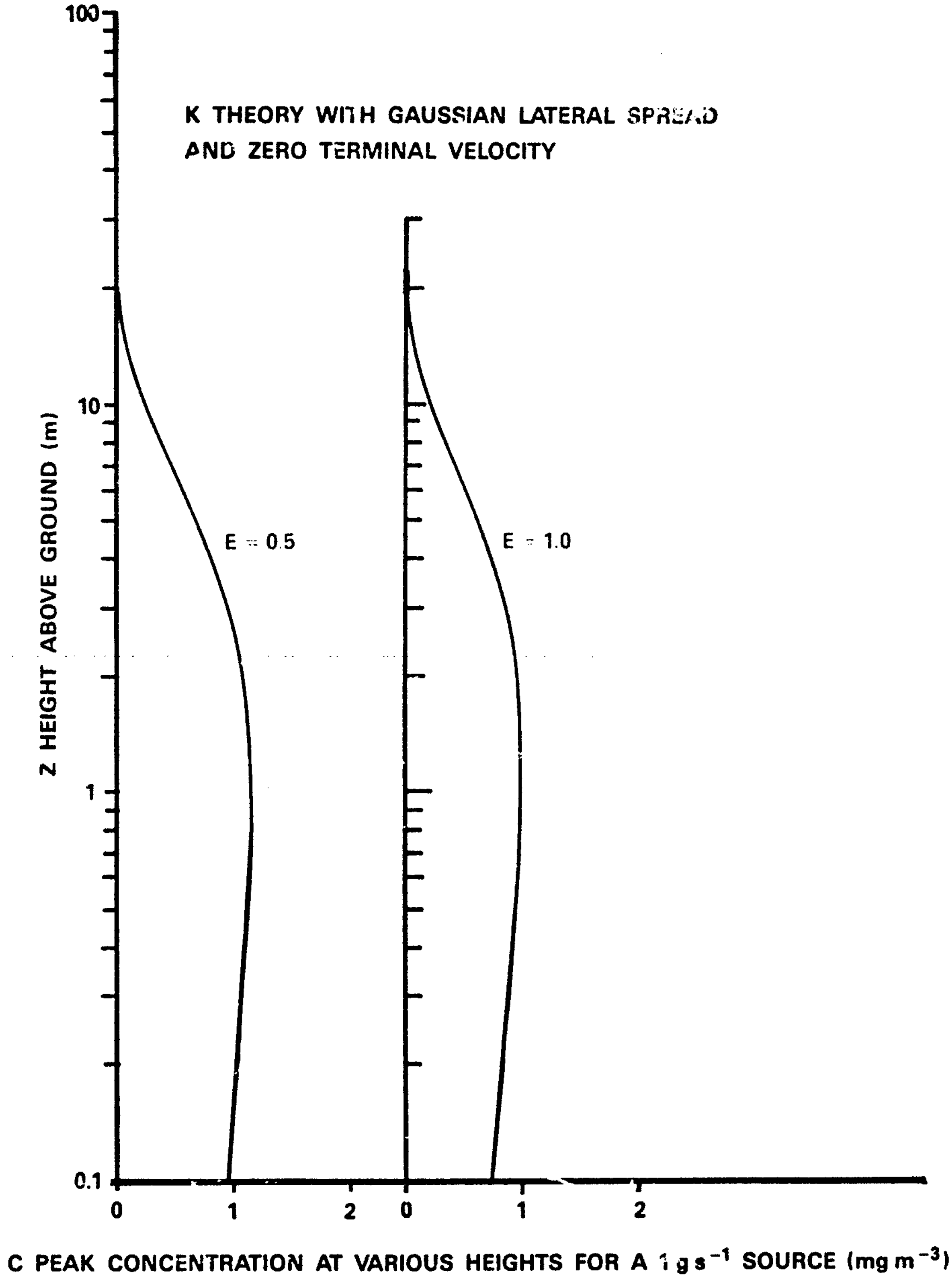


Figure 8

PEAK CONCENTRATIONS 100 m DOWNWIND OF A POINT SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

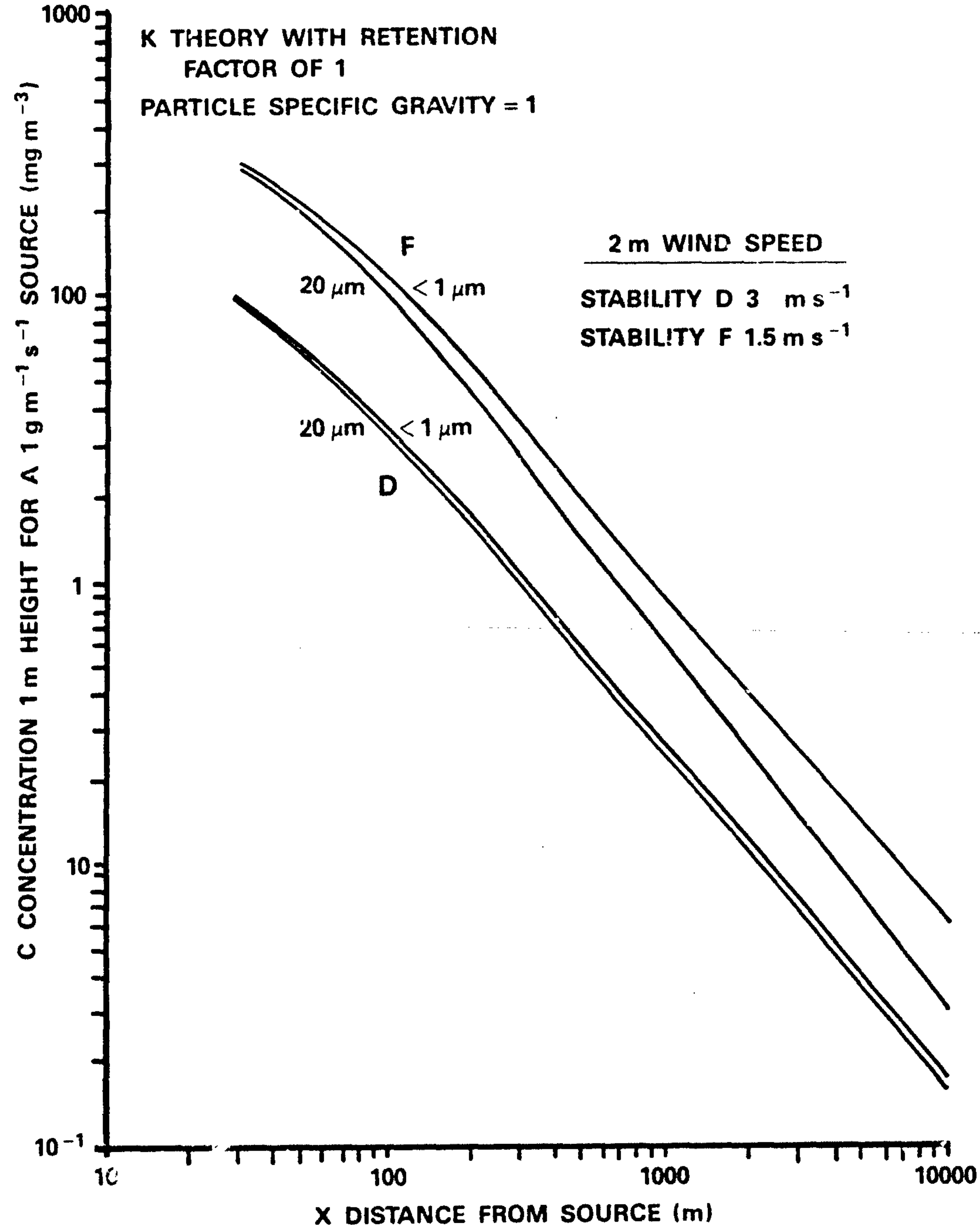


Figure 9

DOWNWIND CONCENTRATIONS OF MONODISPERSE PARTICULATE FROM A LINE SOURCE AT 1 m HEIGHT IN TWO ATMOSPHERIC STABILITY CONDITIONS

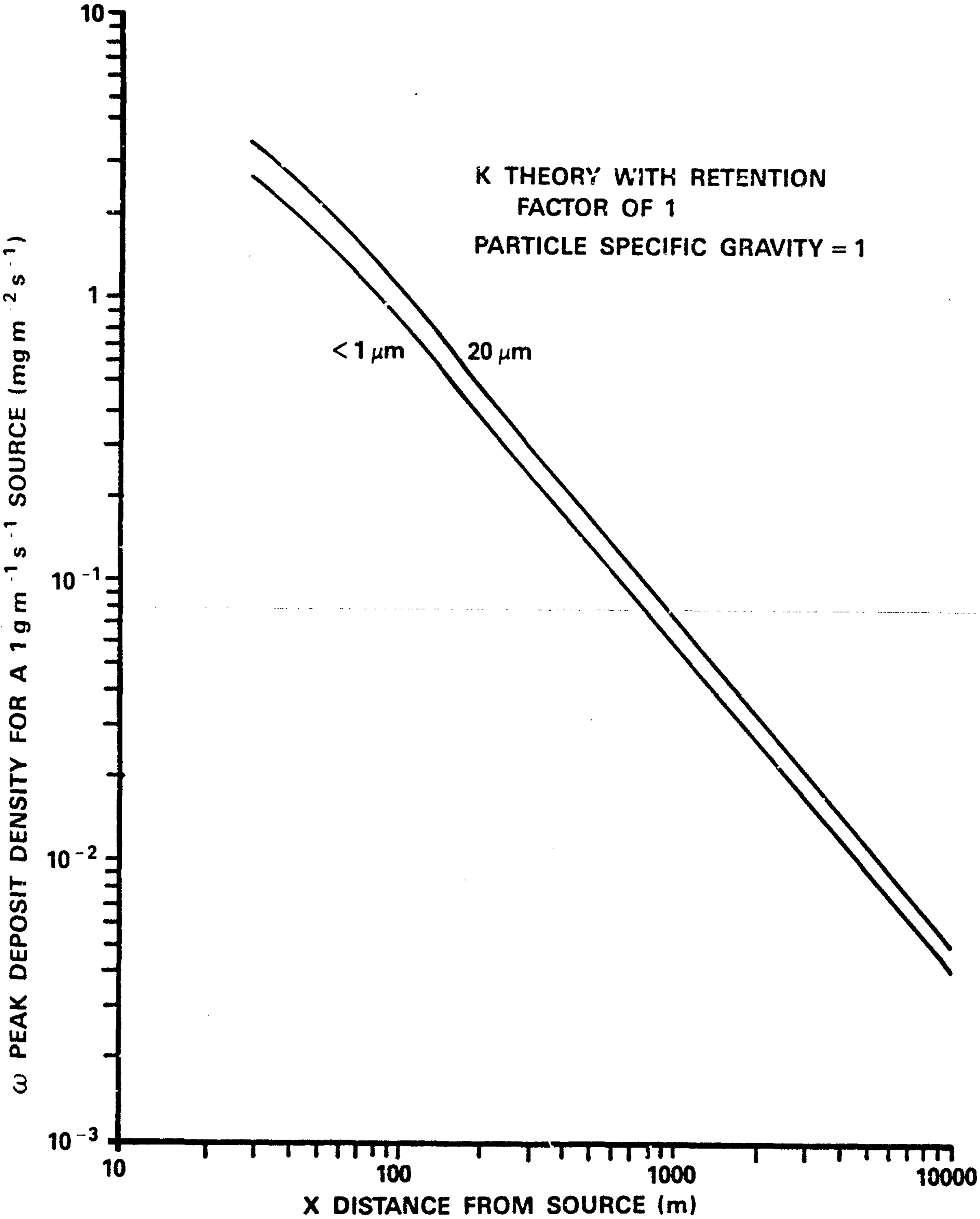


Figure 10

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A LINE SOURCE AT 1 m HEIGHT IN STABILITY CATEGORY D WITH 2 m WIND SPEED OF 3 m s^{-1}

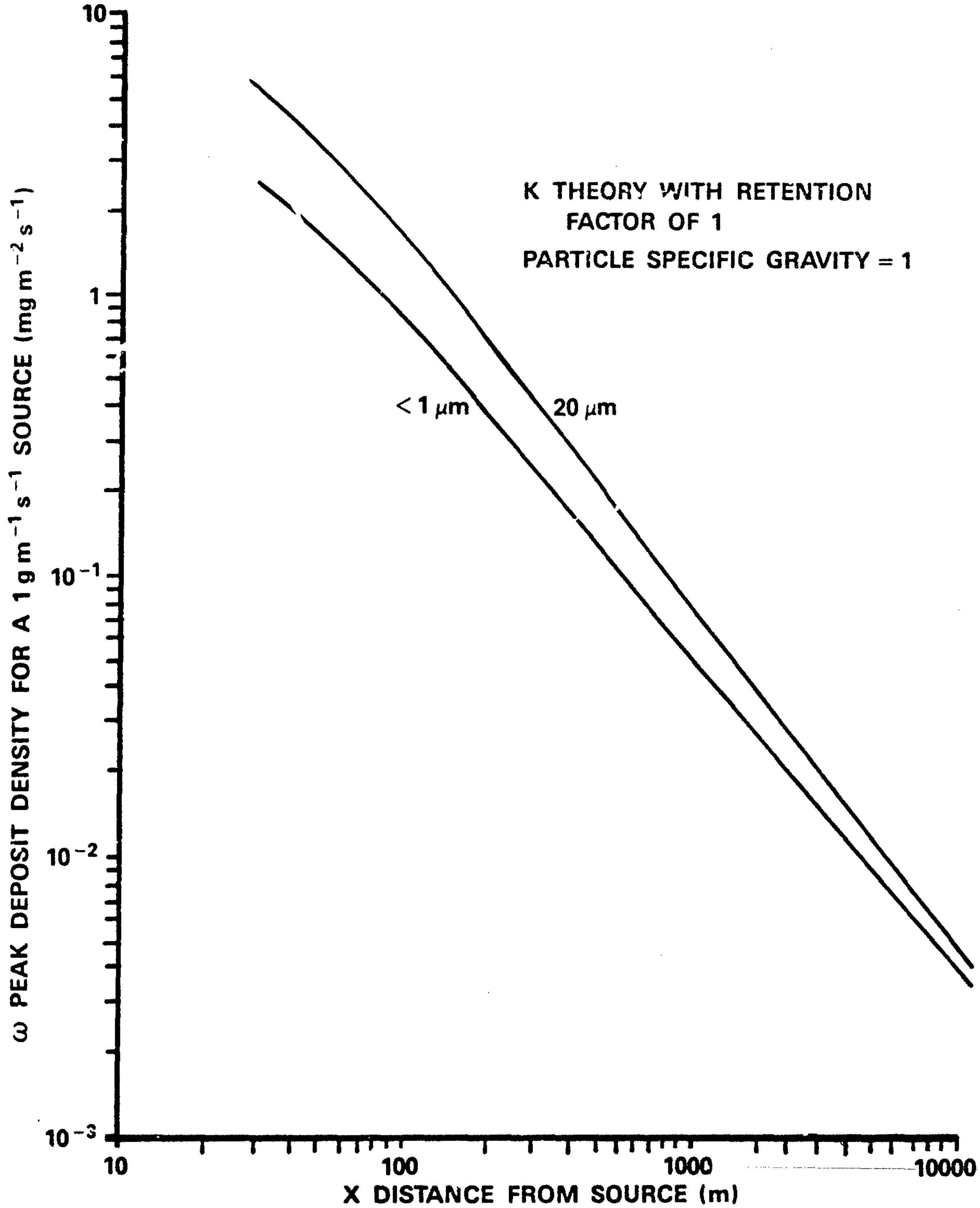


Figure 11

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A LINE SOURCE AT 1 m HEIGHT IN STABILITY CATEGORY F WITH 2 m WIND SPEED OF 1.5 m s^{-1}

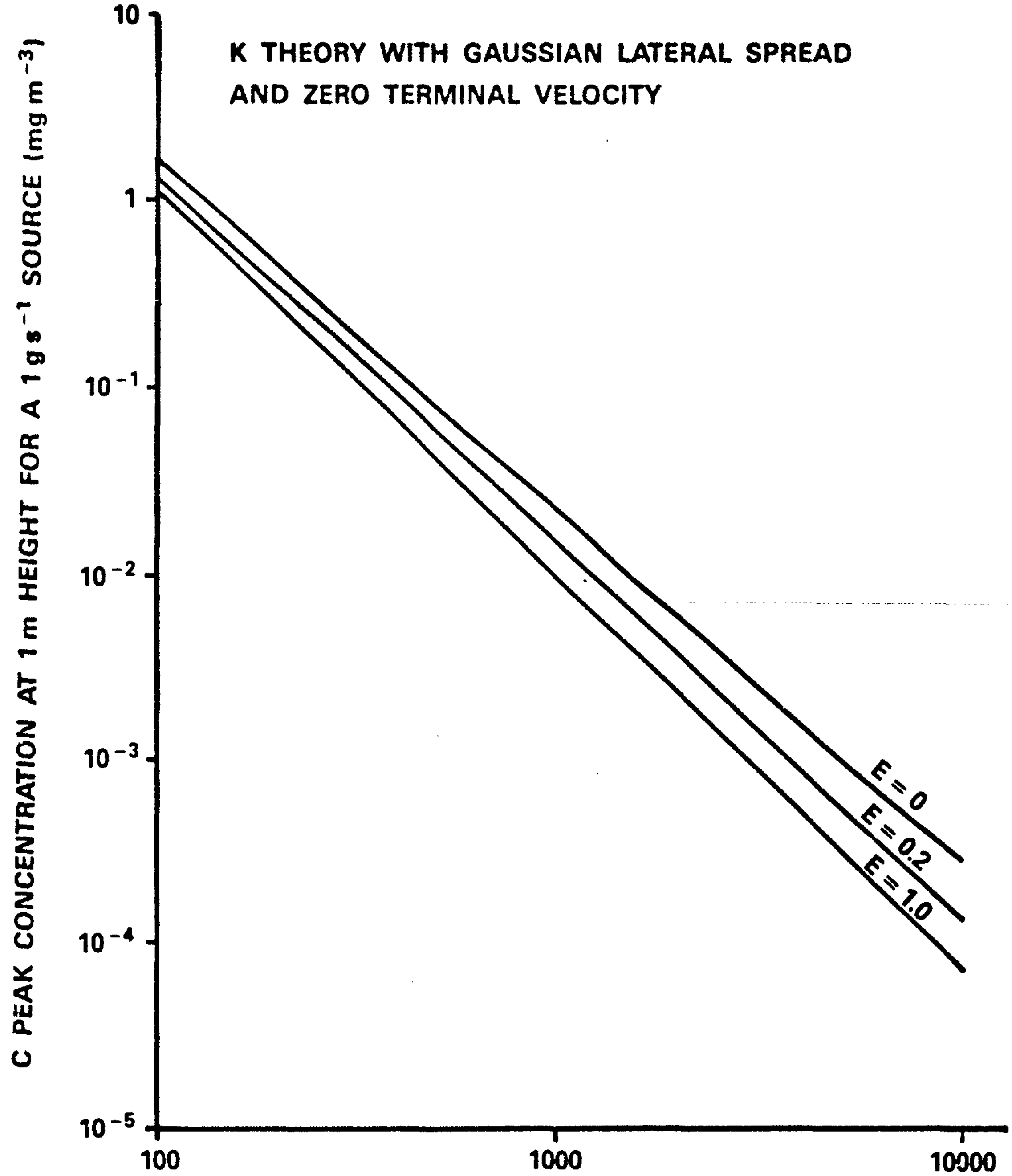


Figure 12

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT 1 m HEIGHT WITH VARIOUS RETENTION EFFICIENCIES IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

UNCLASSIFIED

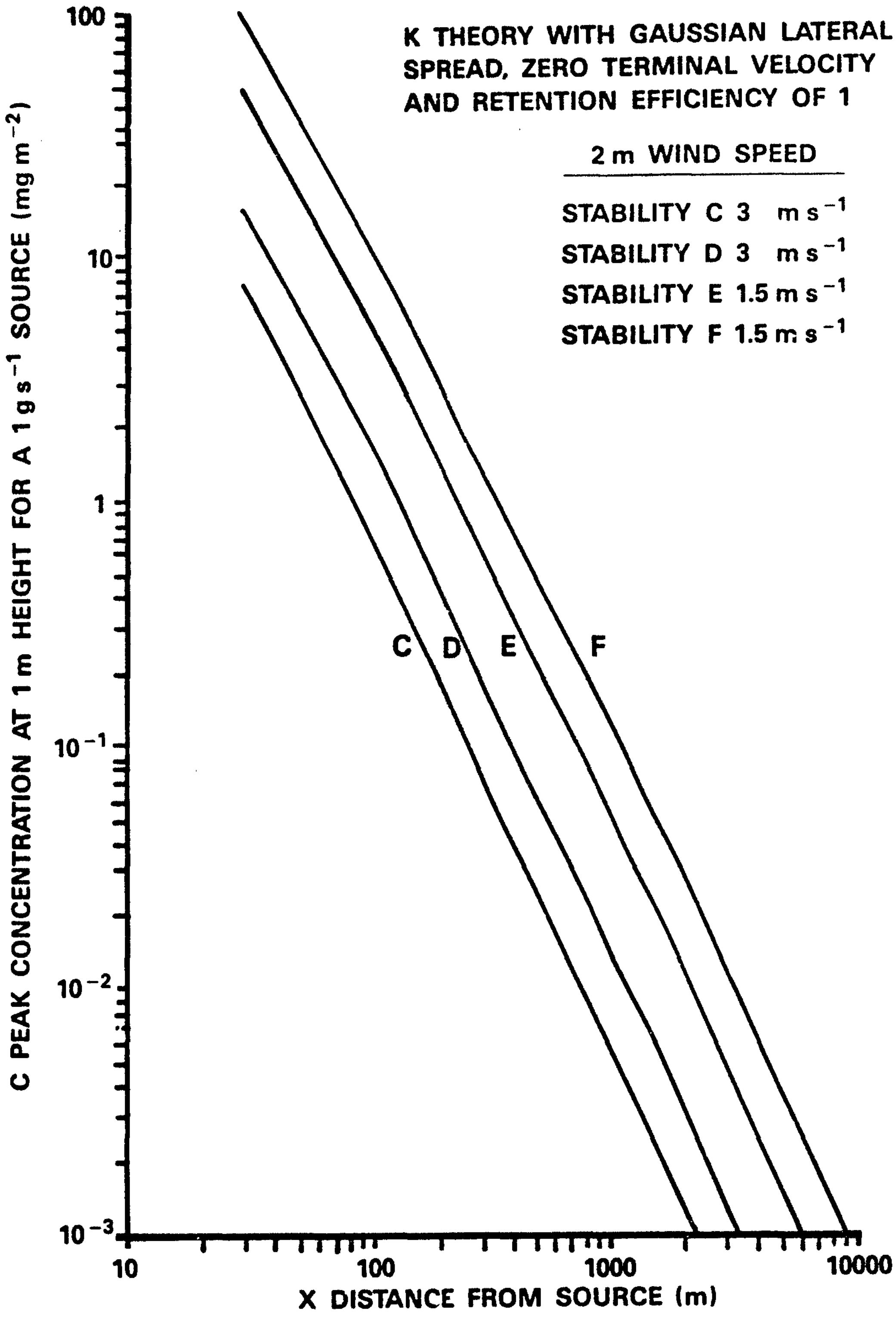


Figure 13

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE AT 1 m HEIGHT IN VARIOUS ATMOSPHERIC STABILITY CONDITIONS

UNCLASSIFIED

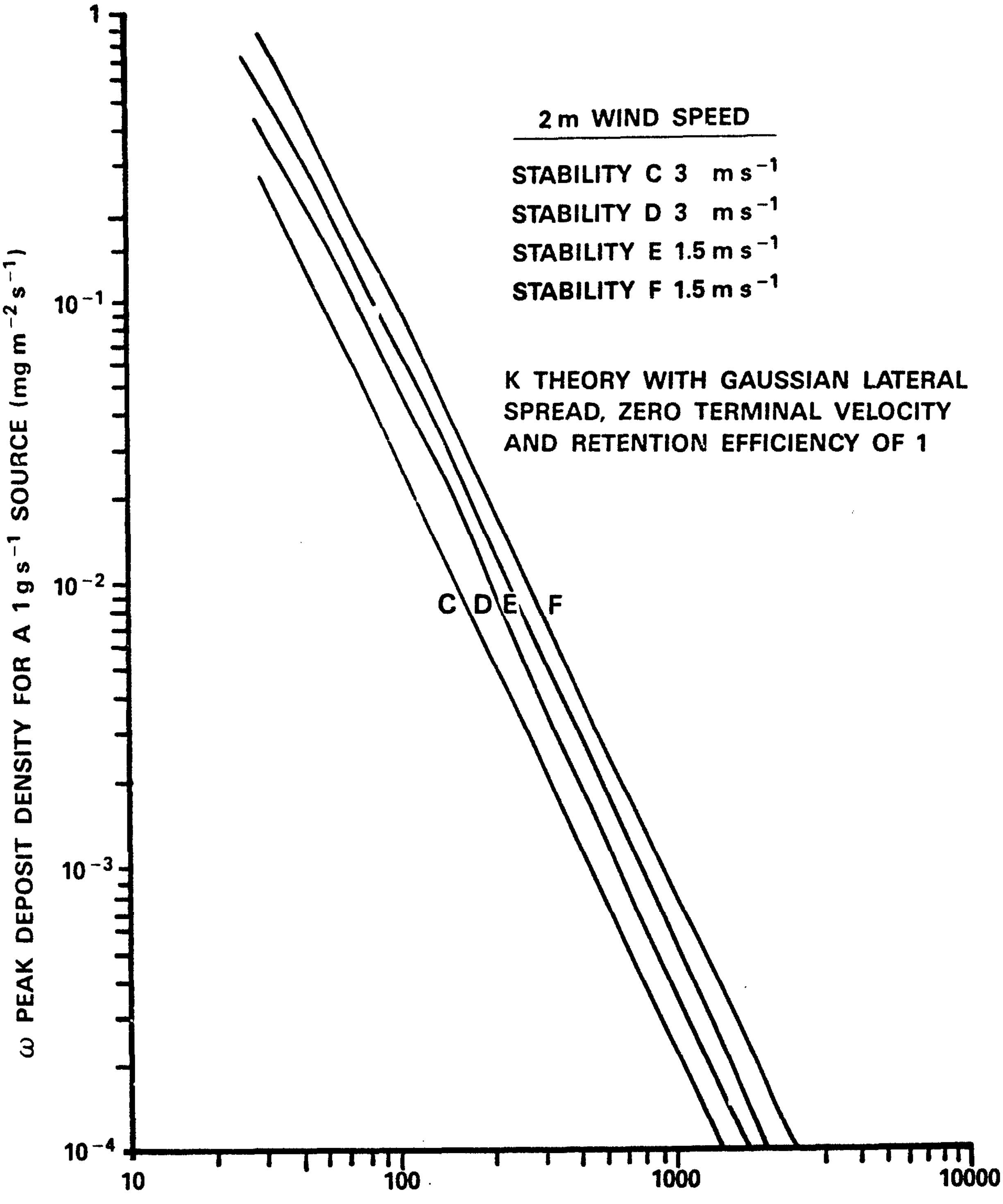


Figure 14

GROUND DEPOSITION FROM A POINT SOURCE AT 1 m HEIGHT IN VARIOUS ATMOSPHERIC STABILITY CONDITIONS

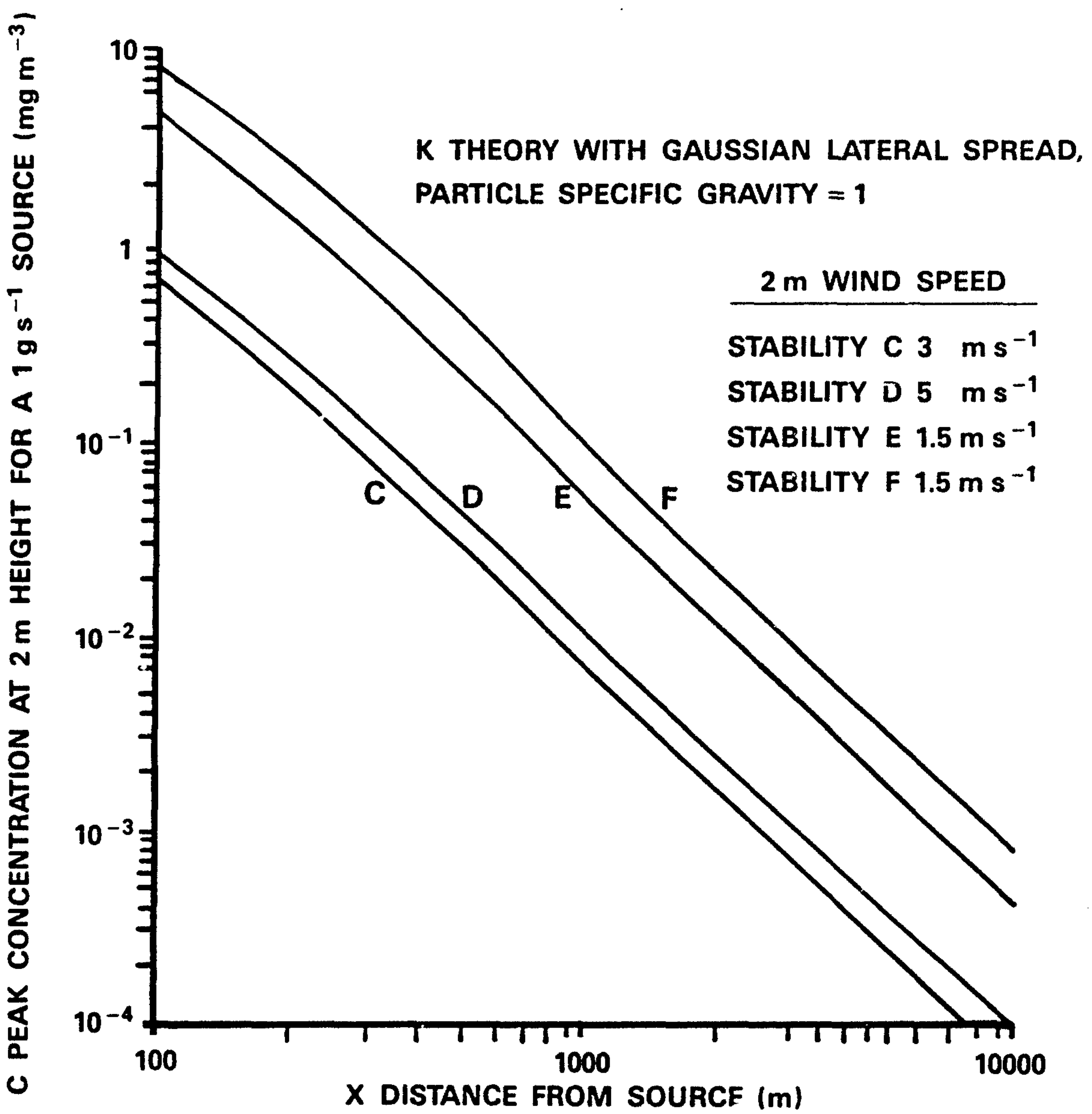


Figure 16

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE OF 20 μm PARTICLES AT 3 m HEIGHT IN VARIOUS ATMOSPHERIC STABILITY CONDITIONS

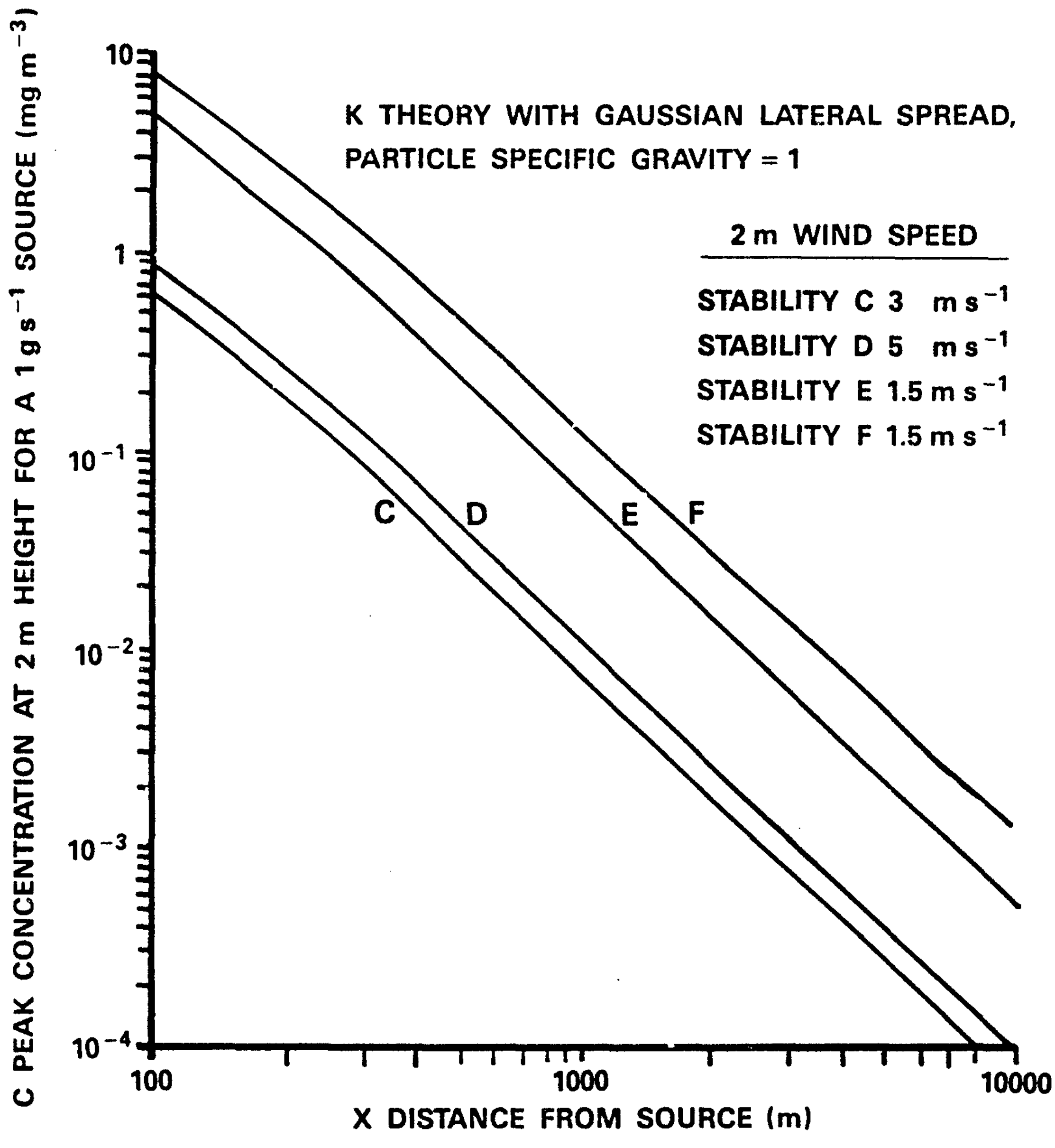


Figure 15

DOWNWIND CONCENTRATIONS FROM A POINT SOURCE OF 5 μm PARTICLES AT 3 m HEIGHT IN VARIOUS ATMOSPHERIC STABILITY CONDITIONS

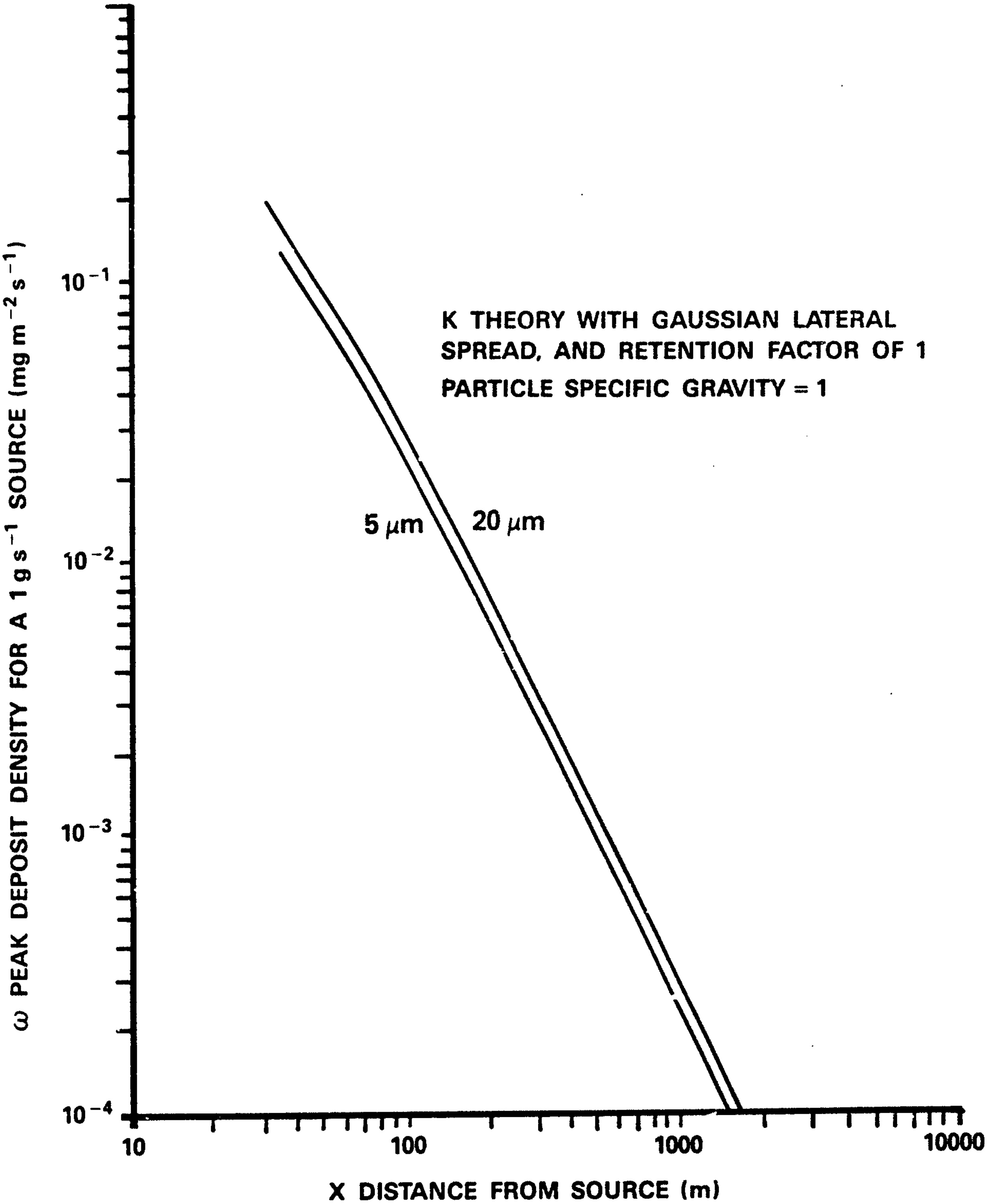


Figure 17

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A POINT SOURCE AT 3 m HEIGHT IN STABILITY CATEGORY C WITH 2 m WIND SPEED OF 3 m s^{-1}

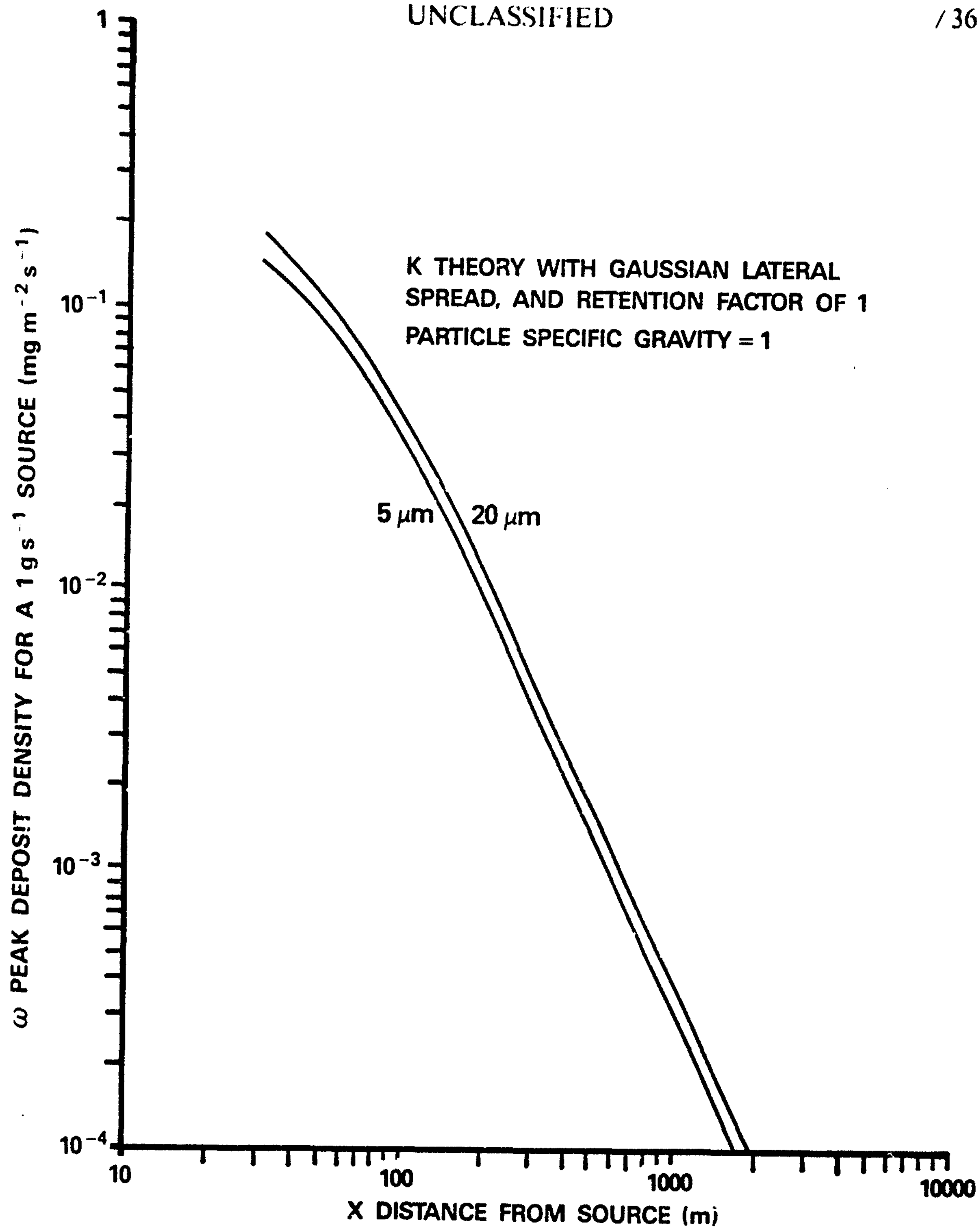


Figure 18

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A POINT SOURCE AT 3 m HEIGHT IN NEUTRAL ATMOSPHERIC STABILITY WITH 2 m WIND SPEED OF 5 m s^{-1}

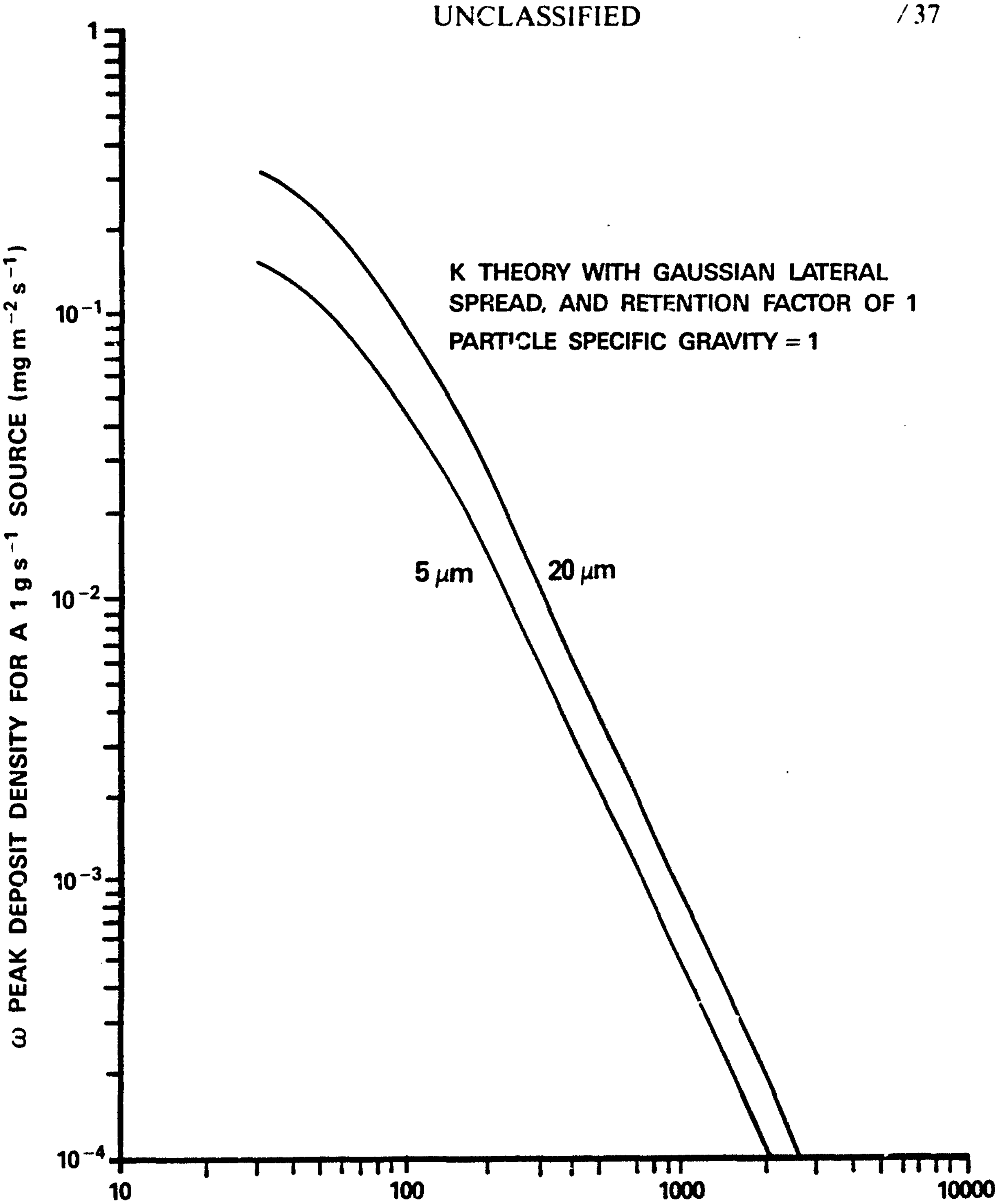


Figure 19

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A POINT SOURCE AT 3 m HEIGHT IN STABILITY CATEGORY E WITH 2 m WIND SPEED OF 1.5 m s^{-1}

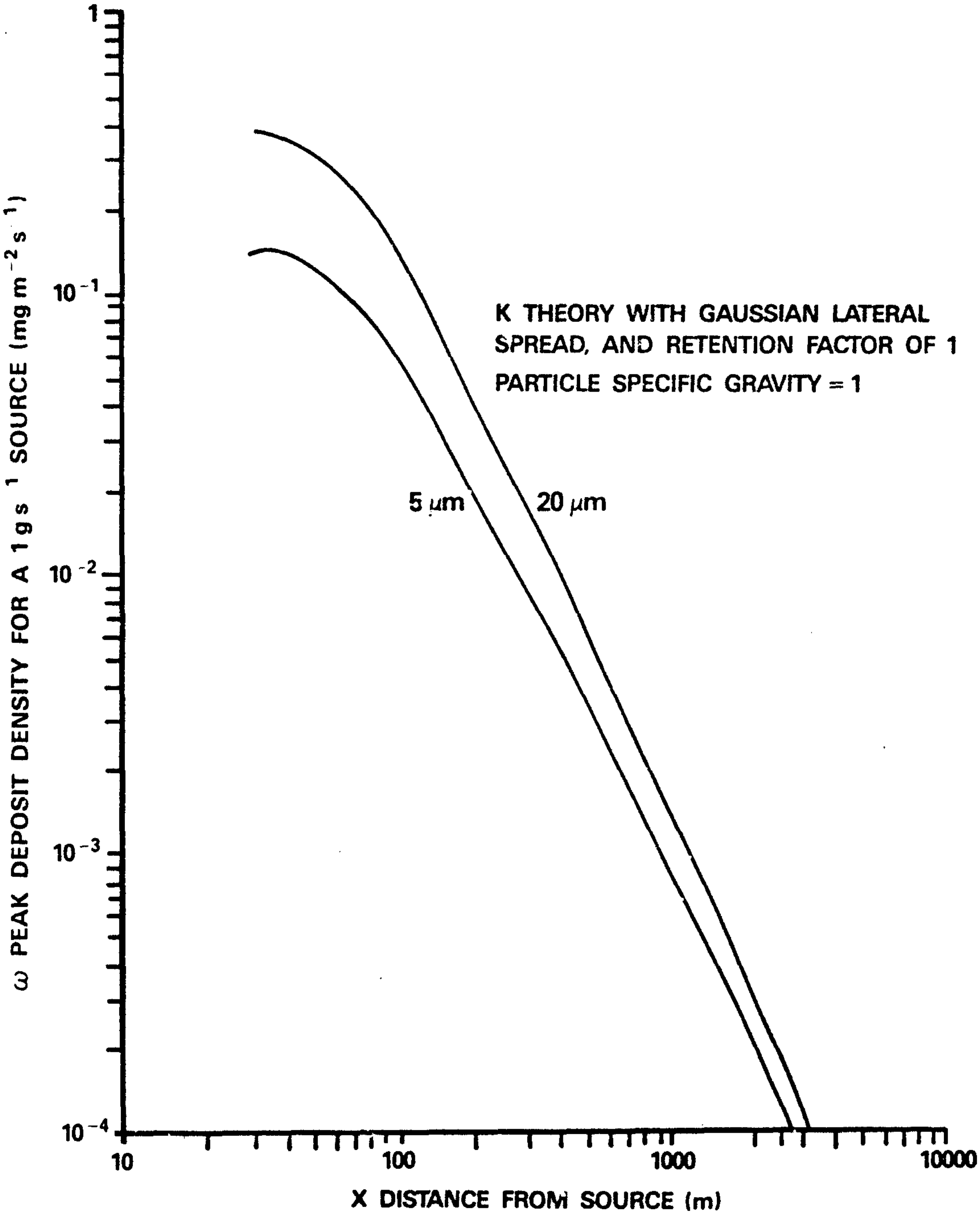


Figure 20

GROUND DEPOSITION OF MONODISPERSE PARTICULATE FROM A POINT SOURCE AT 3 m HEIGHT IN STABILITY CATEGORY F WITH 2 m WIND SPEED OF 1.5 m s^{-1}

DISCUSSION OF RESULTS

23. The results for the K theory line source model agree favorably with Sutton's mean field trial data. As shown in Figure 1, the peak concentration at 100 m downwind is 35 mg m^{-3} for both. At longer downwind distances the calculated results are lower than those given by mean field trial data. The difference gradually increases until at 1000 m the calculated value is 90% of that computed from Sutton's criteria and 70% at 10000 m downwind. The calculated cloud height at 100 m downwind of a line source is 11 m as compared to 10 m from the mean field trial data. The calculated height is obtained from Figure 5, with retention efficiency E = 0, where the concentration has fallen to one-tenth of the value on the ground.

24. The results for the point source model using K theory for vertical dispersion and Gaussian lateral spread agree favorably with the mean field trial data, although less so than for the line source. The calculated peak concentration at 100 m downwind was 1.76 g m^{-3} as compared to 2 g m^{-3} from Sutton's mean field trial data. This corresponds to a calculated value which is 88% of the measured value. The difference gradually increases until the calculated value is 75% of that computed from Sutton's criteria at 1000 m and 50% at 10000 m. The calculated cloud width 100 m downwind of the point source using equation (21) with σ_y from Table II is 34 m, as compared to 35 m from the mean field trial data. The criteria used for the cloud width was that specified by Sutton as the distance between points on the crosswind concentration curve at which the concentration has fallen to one tenth of the peak value. Using the criteria that the cloud width is 4 σ_y, as previously described, the calculated value is 32 m. The cloud height for a point source was not specified for the mean field trial data, but

the calculated value as shown in Figure 7 for retention efficiency, E=0, is the same as for the line source. This is to be expected since the same K theory is used for vertical dispersion.

25. Comparison of Figures 3 and 4 indicate that the downwind location of the maximum ground level concentration for the two methods of calculation is in good agreement for all release heights. The difference in the values of the concentration is greatest for a release height of 20 m where K theory model with Gaussian spread gives results about 75% of that by Gaussian dispersion. The former model tends to give higher concentrations upwind of the peak and lower concentrations downwind of the peak. There is no general agreement on the best method to model elevated sources [8]. A review of various models is described by Gifford [15].

26. The agreement between theory and experiment is favorable for the line source. The calculated results in Figures 5 and 6 also show the behavior of concentration as a function of height for various retention efficiencies. As retention efficiency increases, the height at which the maximum concentration occurs increases, but the maximum concentration, itself decreases. This is also true for a point source as shown in Figures 7 and 8, which uses the same K theory for vertical dispersion.

27. The concentrations at the source height downwind of a low level line source is not affected appreciably by particle size less than 20 μm in neutral atmospheric stability. Figure 9 indicates that the concentrations of 20 μm particles are not less than 90% of the concentrations for particles less than 1 μm in size over the whole downwind distance range considered. For atmospheric stability F, which

is the "worst case", the differences are considerably greater. The reason is that the plume travels close to the ground at all distances, so that even small differences in terminal velocity affect the number of particles which come into contact with the ground and thus are removed by retention. Figure 9 indicates that the difference between concentrations of 20 μm particles and particles less than 1 μm in diameter, gradually increases with downwind distance. The concentrations of 20 μm particles are 85% at 100 m, 65% at 1000 m and 50% at 10000 m of the concentration of particles less than 1 μm in diameter. The ground deposition densities of 20 μm particles are not less than 75% of those of the smallest particles over the whole distance range in atmospheric stability D, but vary gradually from 50% at 100 m to 90% at 10000 m. For the wind speeds considered, which are realistic in practical applications, the ground deposition densities are nearly equal at 10000 m for the two atmospheric stability categories.

28. Figure 12 indicates that concentrations of particles which follow the flow are lower than those of non reacting vapors downwind from a point source. The difference increases gradually as is shown by comparing the results for E=0 and E=1. The concentration for E=0.2 is about midway, on the logarithmic scale, between those for the other two retention efficiencies. Figures 13 and 14 give concentrations and ground deposition densities downwind of a point source using zero terminal velocity. They can be used as a good approximation for particles smaller than 5 μm in diameter. The concentrations for particles between 5 and 20 μm in diameter can be estimated by comparing Figures 15 and 16. A feel for the difference in ground deposition densities downwind of a point source for various small particle sizes is given in Figures 17 to 20, where the calculated results for 5 and 20 μm particles are shown for four atmospheric stability categories.

29. Some comparisons of calculated ground contamination densities for the line source model to field data for particles 30 μm and larger [1,2,16,17] indicate that this model can be used with reasonable confidence. The predicted location of the downwind peak agrees with experiment but the calculated peak ground deposit densities are lower. The point source model which uses the same vertical dispersion function and lower boundary condition is supported by these results to a certain extent, although further experiments would be useful.

CONCLUSIONS

30. A mathematical model has been developed from which concentrations and ground contamination densities from a low level point source of particles less than 20 μm in diameter can be calculated. Confidence in the model to predict concentrations accurately is supported by experimental data for gaseous clouds, for which the model can be applied using the limiting case of zero terminal velocity. Calculations for particles within the specified size range show that the effect of particle size is small enough so that predictions of concentrations can be made with sufficient accuracy for many practical applications. Ground contamination densities can also be calculated for the same range of particle sizes. Reasonable confidence in their accuracy is supported by comparisons with experiments reported previously [1,2,16,17].

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APPENDIX A

COMPUTER PROGRAM

"DIFFP"

WITH SAMPLE RESULTS

A1. The computer program for calculating concentrations and ground contamination densities downwind of a point source using K theory for vertical dispersion and Gaussian lateral dispersion was developed from the line source program. The program called DIFFP is therefore very similar to the program DIFF, from which it was developed. The data input required to execute the program is shown in Table A1, with required atmospheric constants in Table A2. Sample output and a listing of the program immediately follow the table. The program for the line source, which contains several subroutines, is difficult to understand for the uninitiated because it is not thoroughly annotated. The modification to account for lateral spread from a point source was handled as simply and straightforwardly as possible with minimal modifications.

A2. The modifications required to calculate concentrations and ground deposition densities downwind of a point source were all made in the subroutine PPOUT, the last subroutine in the program. A short algorithm was inserted to calculate the standard deviation: σ_y, and the associated Gaussian lateral dispersion function at any distance downwind. The concentrations and ground deposition densities were then obtained by multiplying the concentrations and ground deposition densities for the line source calculated earlier in the program by the lateral dispersion function. The program was set up to calculate results for any one lateral crosswind position, y, at each downwind distance. The peak values are given by setting y = Ø. Off axis values which are symmetric about the axis are less according to the Gaussian lateral distribution.

A3. The algorithm for calculating the Gaussian lateral dispersion function is shown in lines 506 to 526 in the program listing. The modified dosages are calculated in lines 532 to 534 and the modified ground contamination densities are calculated in lines 541 to 543. Line 545 was inserted to include values of the lateral dispersion functions in the output results. Also line 499 was modified to include the new functions in DIMENSION statements and a few FORMAT statements were added.

TABLE A1

DATA INPUT FOR DIFFUSION PROGRAM, DIFFP

RECORD	VARIABLES	FORMAT	NOTES
1	PA,M,S,A,DL, Q,E, SOURC	8F10.0	PA=0.01 U(2). U(2) is 2 m windspeed (m s^{-1}). S=2.0 for open ground; 5.0 for forest. Q is terminal velocity of droplets or particles(m s^{-1}). E is retention factor of substrate; the value is 1 for complete retention SOURC is line source strength, mass per unit length (g m^{-1}). M=p,A, DL=$\Delta\ell$ are given in Table A2).
2	(1) XØ,DY,H, HH, U2M,	8F10.0	XØ is the maximum downwind distance considered. DY = 0.01 (2) H is the height of the atmospheric lid (see Table I). HH is the effective release height (m). U2M is 2 m windspeed (m s^{-1}) (see Table A2.
3	THETA,NZ(IC,ICI)	F10.0,3I3	THETA = 0.5 NZ is the size of the vertical array (usually 48 but $\ngtr$ 100). IC and ICI were used to "debug" the program and to provide auxiliary information: no entry required. Their use is described in foot note (3) below.

TABLE A1

DATA INPUT FOR DIFFUSION PROGRAM, DIFF

continued

RECORD	VARIABLES	FORMAT	NOTES
5	NUMOX,NOVES, (ICZX,IK)	412	NUMOX is the number of down wind distances for output (maximum 20) NOVES is the number of height intervals in print out. This is further described in the notes with record 7. ICZX, IK are used only to provide auxiliary information. No entry is required. Their use is described in foot note (3) below.
6	XOUT(I), I=1,NUMOX	8F10.0	Downwind distance from spray line (m). Maximum number of positions is twenty.
7a,b,c....	STATZ(I), ENDZ(I), ZOUIN(I)	8F10.0	STATZ and ENDZ are bottom and top of chosen interval of height, NOVES. ZOUIN is height increment. Thus 0.0, 10.0, 2.0 will give values of dosage at Z = 0.0, 2.0, 4.0 ....10.0 m. This permits height increments to be varied from one interval to the next. One record is needed for each interval. Total number is NOVES records (not to exceed 25).
8			Not used unless ICZX≥1(3)

TABLE A-1

DATA INPUT FOR DIFFUSION PROGRAM, DIFF

continued

RECORD	VARIABLES	FORMAT	NOTES
9	YC IPSC	F10.0, I3	YC is crosswind coordinate (m). IPSC is 1,2,3,4 for stability categories CDEF.
9	YC IPSC	F10.0, I3	YC is crosswind coordinate (m). IPSC is 1,2,3,4 for stability categories CDEF.

FOOTNOTES

(1) XØ must exceed XOUT(NUMOX) card 6.

(2) The calculated output position may vary slightly from the chosen XOUT(I) in card 6, because DY is a logarithmic increment of downwind distance.

(3) IC = 0, ICI = 0, ICZX = 0, IK = 0
No auxiliary information in output.
IC = 1, ICI = 0, ICZX = 0, IK = 0
Run parameters output
DR NZ DY NY THETA
H HR RH
HH HHR RHH IHH
Matrix constants output
ALPHA BETA GAMMA LAMBA A1 D1
IC = 2, IC1 = 0, ICZX = 0, IK = 0
As for IC = 1 plus:
Output controls
Vertical intervals
START END INCREMENT for each interval
Vertical array
Z RZ ID THETA (portion of full increment for Bessel's interpolation formula)
Horizontal output positions
X X-OUT IY

IC = 3, IC1 ≥ 0, ICZX = 0, IK = 0
As for IC = 2 with the other three variables equal to zero.

IC = 4, IC1 ≥ 0, ICZX ≥ 0, IK ≥ 0
As for IC = 2 and 3 in the two preceding modes, except that no main results are printed out. Moreover, no downwind concentrations and ground contaminations are calculated in the program.

IC = 3, IC1 ≥ 0, ICZX = 0, IK = 0
As for IC = 3 ICI = 0 except that vertical profile and matrix interrogation is printed out for iteration intervals separated by the value of ICI. For example, if ICI = 10, iterations 10, 20, 30.....are printed out until the specified maximum value of downwind distance has been reached. This mode results in a large array of numbers printed out at each iteration determined by ICI and could result in a great deal of output paper from the printer.

IC = 2, IC1 = 0, ICZX ≥ 0, IK ≥ 0

ICZX = 1: Peak concentrations and vertical locations of peaks in the transformed plane for downwind positions IK·DY starting at Y = DY are printed out. For example, if DY = 0.01, IK = 3, values are printed out at DY = 0.01, 0.04, 0.07.....

ICZX = 2: As for ICZX = 1 except that concentrations are also given at one user specified height, Z, at the same downwind positions. An extra data record is needed if ICZX ≥ 1, which specifies heights Z, as follows. XZ(I), FORMAT 2F10.0. Only one value of ZX(I) is required if ICZX = 2.

ICZX = 3: As for ICZX = 2 except that concentrations are printed out at two user specified heights, Z. Peak concentrations are not given.

TABLE A2

VALUES OF CONSTANTS

CONSTANTS

STABILITY CATEGORY	A	$\Delta\ell$ (m)	p	u(2) ($m\ s^{-1}$)	H (m)
C	0.08	0.025	0.2	2-4	1000
D	0.04	0.025	0.23	≥3	500
E	0.03	0.025	0.3	1.5-3	200
F	0.02	0.025	0.5	1.5-2	100

$\Delta\ell$ is given for grassland

A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWNWIND
TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FROM AN ELEVATED SOURCE

```
STABILITY D,  0 MICRONS        E=1.0,  HH=1.0, NZ=96, DY=0.001

                 PA=   .03000     (AIR PERMEABILITY)
                 M=    .25        (WIND PROFILE PARAMETER)
                 S = 2.000        (TOTAL SPECIFIC AREA)
                 A =   .0400      (VON KARMANS CONSTANT/10)
                 DL =   .025      (ROUGHNESS LENGTH)
                 Q = .00000       (TERMINAL VELOCITY)
                 E =   1.000      (RETENTION FACTOR)
                 SOURC= 1000.00   (SOURCE STRENGTH)
                 U(2)= 3.00       (2 METRE WIND)
```

H ATMOSPHERIC LID	HH RELEASE HEIGHT	XO DOWNWIND DISTANCE
500.000	1.000	11000.000

```
YC =      .0    (CROSSWIND COORDINATE)
IPSC =  2       (STABILITY CATEGORY INDICATOR)
IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.
```

DOWNWIND CONCENTRATIONS

	X	X	X	X
	29.86	40.02	49.83	59.82
VERTICAL GRID Z(I)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	7.337733	5.255587	2.781650	1.934432
.10	13.066868	7.594209	4.972005	3.462055
.20	14.884575	8.678974	5.696511	3.974404
.30	15.302993	9.250112	6.089270	4.258229
.40	16.291758	9.577352	6.325249	4.434517
.50	16.523041	9.758921	6.467836	4.546911
.60	16.581516	9.842765	6.547793	4.616496
.70	16.516153	9.856387	6.582653	4.655234
.80	16.358392	9.817297	6.583528	4.670656
.90	16.129939	9.737484	6.557952	4.667861
1.00	15.846604	9.625610	6.511355	4.650494
2.00	11.750143	7.691420	5.477157	4.067045
3.00	7.666650	5.523948	4.185252	3.253541
4.00	4.622694	3.730556	3.033898	2.482837
5.00	2.623734	2.408656	2.118716	1.833947
6.00	1.418280	1.500120	1.436733	1.320847
7.00	.736261	.906541	.950747	.931712
8.00	.369525	.533917	.616125	.645658
9.00	.180352	.307576	.392081	.440566
10.00	.086031	.173848	.245566	.296554
15.00	.001743	.008228	.019820	.035033
20.00	.000033	.000334	.001347	.003497
25.00	.000001	.000014	.000087	.000324
30.00	.000000	.000001	.000006	.000030
MASS IN AIR	90.558710	88.204316	86.397723	84.882037
MASS ON GROUND	9.434784	11.790629	13.598165	15.114532
TOTAL	99.993494	99.994945	99.995868	99.996569
DEPOSIT DENSITY	.440264	.255335	.166899	.116066
CROSSWIND FUNCTION	.167268	.124853	.100326	.083618

DOWNWIND CONCENTRATIONS

VERTICAL GRID Z(I)	X 79.76 CONCENTRATION	X 99.81 CONCENTRATION	X 199.67 CONCENTRATION	X 400.19 CONCENTRATION
.00	1.077891	.677672	.156898	.035505
.10	1.932568	1.216443	.282361	.063985
.20	2.224671	1.402851	.326919	.074241
.30	2.391218	1.511071	.353765	.080537
.40	2.499057	1.582909	.372470	.035029
.50	2.572178	1.633314	.386432	.088477
.60	2.622097	1.669435	.397262	.091241
.70	2.655303	1.695282	.405856	.093520
.80	2.675854	1.713350	.412767	.095436
.90	2.686475	1.725308	.418359	.097089
1.00	2.689103	1.732334	.422887	.098476
2.00	2.480591	1.654677	.435606	.105664
3.00	2.111311	1.466089	.420918	.106994
4.00	1.725566	1.252292	.395302	.105754
5.00	1.372635	1.044475	.364874	.103058
6.00	1.069763	.855850	.332711	.099559
7.00	.820011	.691450	.300563	.095497
8.00	.619830	.552054	.269478	.091113
9.00	.462865	.436290	.240078	.086554
10.00	.341968	.341722	.212717	.081922
15.00	.066352	.090592	.109000	.059745
20.00	.011104	.021121	.051664	.041533
25.00	.001704	.004529	.023153	.027914
30.00	.000251	.000923	.009942	.018276
MASS IN AIR	82.503744	80.675738	75.277887	70.354345
MASS ON GROUND	17.493709	19.322260	24.721189	29.645238
TOTAL	99.997453	99.997998	99.999076	99.999584
DEPOSIT DENSITY	.064673	.040660	.009414	.002130
CROSSWIND FUNCTION	.062774	.050213	.025223	.012708

DOWNWIND CONCENTRATIONS

	X	X	X	X
	599.50	800.64	1000.58	1998.91
VERTICAL GRID Z(I)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	.014961	.008074	.005030	.001176
.10	.026974	.014562	.009072	.002121
.20	.031321	.016914	.010540	.002466
.30	.034006	.018372	.011451	.002680
.40	.035936	.019424	.012110	.002836
.50	.037431	.020243	.012624	.002958
.60	.038641	.020908	.013044	.003058
.70	.039650	.021467	.013397	.003143
.80	.040510	.021945	.013700	.003217
.90	.041252	.022361	.013965	.003281
1.00	.041902	.022727	.014199	.003339
2.00	.045590	.024903	.015624	.003705
3.00	.046906	.025831	.016285	.003900
4.00	.047177	.026211	.016613	.004021
5.00	.046851	.026278	.016749	.004100
6.00	.046142	.026139	.016760	.004152
7.00	.045172	.025857	.016683	.004185
8.00	.044021	.025472	.016541	.004203
9.00	.042743	.025009	.016349	.004210
10.00	.041375	.024487	.016118	.004208
15.00	.034033	.021417	.014620	.004108
20.00	.026964	.018130	.012885	.003922
25.00	.020826	.015036	.011147	.003695
30.00	.015775	.012270	.009511	.003449
MASS IN AIR	67.729655	65.954220	64.642622	60.863346
MASS ON GROUND	32.270083	34.045592	35.357232	39.136524
TOTAL	99.999738	99.999812	99.999854	99.999870
DEPOSIT DENSITY	.000898	.000484	.000302	.000071
CROSSWIND FUNCTION	.008564	.006473	.005227	.002733

DOWNWIND CONCENTRATIONS

	X	X	X	X
	3998.99	6000.33	7998.19	10005.02
VERTICAL GRID Z(I)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	.000284	.000127	.000072	.000047
.10	.000513	.000229	.000131	.000085
.20	.000596	.000266	.000152	.000099
.30	.000648	.000289	.000165	.000108
.40	.000686	.000306	.000175	.000114
.50	.000716	.000320	.000183	.000119
.60	.000741	.000331	.000189	.000123
.70	.000761	.000340	.000194	.000127
.80	.000779	.000348	.000199	.000130
.90	.000795	.000355	.000203	.000132
1.00	.000810	.000362	.000207	.000135
2.00	.000902	.000404	.000231	.000151
3.00	.000954	.000427	.000245	.000160
4.00	.000989	.000444	.000254	.000166
5.00	.001014	.000456	.000262	.000171
6.00	.001034	.000466	.000267	.000175
7.00	.001048	.000473	.000272	.000178
8.00	.001060	.000479	.000276	.000181
9.00	.001069	.000484	.000279	.000183
10.00	.001075	.000489	.000282	.000185
15.00	.001089	.000501	.000291	.000191
20.00	.001083	.000505	.000295	.000195
25.00	.001064	.000503	.000296	.000196
30.00	.001039	.000499	.000296	.000197
MASS IN AIR	57.448135	55.431580	53.826098	52.456897
MASS ON GROUND	42.523803	44.341965	45.563396	46.479138
TOTAL	99.971938	99.773545	99.389494	98.936035
DEPOSIT DENSITY	.000017	.000008	.000004	.000003
CROSSWIND FUNCTION	.001475	.001051	.000836	.000705

```
       A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWNWIND
TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FROM AN ELEVATED SOURCE

STABILITY D,  20 MICRONS      E=1.0,  HH=1.0, NZ=96, DY=0.001

                   PA=  .03000    (AIR PERMEABILITY)
                   M=    .23      (WIND PROFILE PARAMETER)
                   S = 2.000      (TOTAL SPECIFIC AREA)
                   A =  .0400     (VON KARMANS CONSTANT/10)
                   DL =  .025     (ROUGHNESS LENGTH)
                   Q = .01216     (TERMINAL VELOCITY)
                   E =  1.000     (RETENTION FACTOR)
                   SOURC= 1000.00 (SOURCE STRENGTH)
                   U(2)= 3.00     (2 METRE WIND)

                         H           HH         XO
                    ATMOSPHERIC   RELEASE   DOWNWIND
                        LID        HEIGHT   DISTANCE

                      500.000      1.000 11000.000
```

```
YC =      .0    (CROSSWIND COORDINATE)
IPSC =  2       (STABILITY CATEGORY INDICATOR)
IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.
```

DOWNWIND CONCENTRATIONS

	X 29.86	X 40.02	X 49.83	X 59.82
VERTICAL GRID Z(I)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	8.135571	4.694683	3.057705	2.120272
.10	13.958597	8.072143	5.266077	3.656268
.20	15.571646	9.034967	5.909110	4.110834
.30	16.305073	9.497727	6.230181	4.344209
.40	16.635822	9.732923	6.405420	4.477802
.50	16.732376	9.836148	6.496283	4.553800
.60	16.675553	9.852896	6.531843	4.592068
.70	16.511227	9.808772	6.528359	4.603560
.80	16.268412	9.719830	6.495962	4.595427
.90	15.966892	9.596924	6.441455	4.571947
1.00	15.620917	9.447810	6.369675	4.536460
2.00	11.263195	7.345935	5.214996	3.861848
3.00	7.232477	5.192639	3.922775	3.041425
4.00	4.312238	3.468697	2.812483	2.295928
5.00	2.428414	2.221616	1.948504	1.632136
6.00	1.305177	1.375151	1.313011	1.203802
7.00	.674676	.827063	.864536	.944800
8.00	.337558	.485291	.558003	.582976
9.00	.164374	.278748	.353937	.396418
10.00	.078281	.157194	.221089	.266070
15.00	.001581	.007400	.017716	.031164
20.00	.000030	.000300	.001202	.003102
25.00	.000001	.000012	.000078	.000287
30.00	.000000	.000001	.000005	.000027
MASS IN AIR	87.207223	84.075493	81.682702	79.681698
MASS ON GROUND	12.785572	15.918937	18.312783	20.314545
TOTAL	99.992794	99.994429	99.995485	99.996243
DEPOSIT DENSITY	.587063	.338768	.220644	.152999
CROSSWIND FUNCTION	.167268	.124853	.100326	.083618

DOWNWIND CONCENTRATIONS

	X	X	X	X
	79.76	99.81	199.67	400.19
VERTICAL GRID Z(I)	CONCENTRATION	CONCENTRATION	CONCENTRATION	CONCENTRATION
.00	1.176233	.737020	.168921	.037845
.10	2.031947	1.274695	.292897	.065710
.20	2.290852	1.439711	.332113	.074666
.30	2.428686	1.529556	.354457	.079887
.40	2.512254	1.585871	.369367	.083475
.50	2.564638	1.622992	.380068	.086145
.60	2.596639	1.647596	.388051	.088227
.70	2.614223	1.663359	.394125	.089900
.80	2.621062	1.672529	.398785	.091270
.90	2.6195[illegible]1	1.676592	.402350	.092408
1.00	2.611[illegible]20	1.676583	.405042	.093363
2.00	2.345030	1.558801	.406011	.097463
3.00	1.964956	1.359630	.386104	.097105
4.00	1.588581	1.148721	.358556	.094895
5.00	1.253335	.950181	.328123	.091678
6.00	.970464	.773477	.297136	.087907
7.00	.739969	.621527	.266887	.083815
8.00	.556876	.493989	.238118	.079556
9.00	.414319	.388903	.211246	.075235
10.00	.305141	.303603	.186479	.070925
15.00	.058609	.079599	.094292	.050963
20.00	.009763	.018452	.044327	.0[illegible]5081
25.00	.001495	.003946	.019759	.023413
30.00	.000220	.000803	.008455	.015248
MASS IN AIR	76.553376	74.158229	67.132959	60.788980
MASS ON GROUND	23.443847	25.839596	32.866047	39.210576
TOTAL	99.997223	99.997825	99.999006	99.999556
DEPOSIT DENSITY	.084877	.053183	.012189	.002731
CROSSWIND FUNCTION	.062774	.050213	.025223	.012708

DOWNWIND CONCENTRATIONS

VERTICAL GRID Z(I)	X 599.50 CONCENTRATION	X 800.64 CONCENTRATION	X 1000.58 CONCENTRATION	X 1998.91 CONCENTRATION
.00	.015854	.008520	.005290	.001224
.10	.027540	.014804	.009193	.002127
.20	.031316	.016840	.010459	.002422
.30	.033534	.018041	.011208	.002596
.40	.035073	.018877	.011731	.002719
.50	.036231	.019511	.012128	.002813
.60	.037145	.020014	.012445	.002898
.70	.037392	.020427	.012706	.002951
.80	.038513	.020775	.012927	.003004
.90	.039040	.021072	.013116	.003050
1.00	.039492	.021329	.013281	.003091
2.00	.041300	.022735	.014216	.003336
3.00	.042312	.023200	.0145[illegible]7	.003455
4.00	.042068	.023270	.014699	.003520
5.00	.041405	.023120	.014687	.003557
6.00	.040483	.022830	.014589	.003576
7.00	.039390	.022445	.014432	.003582
8.00	.038185	.021993	.014232	.003578
9.00	.036905	.021493	.014001	.003567
10.00	.035579	.020958	.013745	.003550
15.00	.028816	.018040	.012271	.003410
20.00	.022594	.015115	.010697	.003213
25.00	.017316	.012431	.009177	.003005
30.00	.013039	.010080	.007779	.002785
MASS IN AIR	57.433974	55.175961	53.514113	48.757586
MASS ON GROUND	42.565748	44.823840	46.485733	51.242295
TOTAL	99.999722	99.999801	99.999846	99.999881
DEPOSIT DENSITY	.001144	.000615	.000382	.000093
CROSSWIND FUNCTION	.008564	.006473	.005227	.002733

DOWNWIND CONCENTRATIONS

VERTICAL GRID Z(I)	X 3998.99 CONCENTRATION	X 6000.33 CONCENTRATION	X 7998.19 CONCENTRATION	X 10005.02 CONCENTRATION
.00	.000293	.000130	.000074	.000048
.10	.000509	.000226	.000128	.000083
.20	.000579	.000257	.000146	.000095
.30	.000621	.000276	.000157	.000102
.40	.000651	.000289	.000164	.000107
.50	.000674	.000299	.000170	.000110
.60	.000692	.000307	.000175	.000113
.70	.000707	.000314	.000179	.000116
.80	.000720	.000319	.000182	.000118
.90	.000732	.000325	.000185	.000120
1.00	.000742	.000329	.000187	.000122
2.00	.000804	.000357	.000203	.000132
3.00	.000836	.000372	.000212	.000135
4.00	.000857	.000382	.000218	.000142
5.00	.000871	.000389	.000222	.000145
6.00	.000881	.000394	.000225	.000147
7.00	.000887	.000398	.000228	.000148
8.00	.000892	.000401	.000230	.000150
9.00	.000895	.000403	.000231	.000151
10.00	.000897	.000405	.000233	.000152
15.00	.000894	.000409	.000236	.000155
20.00	.000878	.000407	.000237	.000156
25.00	.000856	.000402	.000235	.000156
30.00	.000829	.000395	.000233	.000155
MASS IN AIR	44.518177	42.128112	40.347681	38.893413
MASS ON GROUND	55.461018	57.706082	59.206017	60.325947
TOTAL	99.979195	99.834194	99.553698	99.219360
DEPOSIT DENSITY	.000021	.000009	.000005	.000003
CROSSWIND FUNCTION	.001475	.001051	.000836	.000705

```
C
C
C      STARTED DIFFP FROM DIFF JAN21/87
C
C      EDITOR TEST MAY 25/83
       REAL M,LAMA
       DIMENSION ZZ(25),ID(25),RD(25),ZX(2),IR(2),RIR(2),YOUT(20),IY(20)
       DIMENSION CS(25),30(25,7),PERA(20),PERG(20),TOT(20),DOSE(25,4)
       DIMENSION CD(20)
       COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
       COMMON CV(100),RZ(100)
C
C      MAINLINE PROGRAM FOR PARTICULATE DIFFUSION
     6 READ(5,100) PA,M,S,A,DL,Q,E,SOURC
       IF(M)1,1,2
     1 CALL EXIT
     2 READ(5,100) XO,DY,H,HH,U2M
       READ(5,101) THETA,NZ,IC,IC1
       NY= IFIX(ALOG(XC/H + 1)/DY + 0.01)
       IF(U2M) 3,3,4
     3 U2M=1.0
     4 CALL PPARM(XO)
       CALL PCONS(THETA,NY,RH,RHH,IL,ALPA,BETA,GAMA,LAMA,A11,D11)
       CALL POUTP(IC,IK,INN,ZZ,ID,RD,ICZX,ZX,IR,RIR,IY,YOUT,NUMOX)
       I1=1
       I2=0
       J1=1
       J2=1
       J3=0
C
C
       GRDM=0.0
       GRDM1=0.0
       WRITE(6,102)
   102 FORMAT(1H1)
       IF(IC-4) 5,6,6
     5 DO 7 J=1,NY
       J3=J3+1
       CALL PTRID(J,ALPA,BETA,GAMA,LAMA,A11,D11,THETA,IC,IC1,J3)
       CALL PMBAG(ICZX,RH,RHH,AIRM,GRDM,GRDM1,PERAR,PERGD,TOTAL,PEAK,PZ,
      1 CS,COFAC,IR,RIR,J)
C
C
       IF(ICZX) 8,8,9
     9 IF(J-I1) 8,10,10
    10 I1=I1+IK
```

```
      I2=I2+1
      CALL PBALO(ICZX,I2,PEAK,PZ,CS,J,DY,PERAR,PERGD,TOTAL,COFAC,ZX,80)
    8 IF(J2-NUMOX) 11,11,12
   11 IF(J-IY(J2)) 12,13,18
   13 PERA(J2)=PERAR
      PERG(J2)=PERGD
      TOT(J2)=TOTAL
      CALL BESIN(CV,NZ,ID,RD,INN,CS)
      CD(J1)=CS(1)*COFAC*U2M*A*E*(PA+Q/S)*S
      DO 14 I=1,INN
      DOSE(I,J1)=CS(I)*COFAC
   14 CONTINUE
      IF(J1-4) 15,16,16
   15 IF(J2-NUMOX) 17,16,16
   16 CALL PPOUT(J1,J2,DOSE,ZZ,INN,YOUT,PERA,PERG,TOT,CD)
      J1=0
   17 J1=J1+1
      J2=J2 + 1
      GO TO 12
   18 CONTINUE
      WRITE (5,103)
      GO TO 6
   12 CONTINUE
    7 CONTINUE
      GO TO 6
  100 FORMAT(8F10.0)
  101 FORMAT(F10.0,3I3)
  103 FORMAT(1H1,4X,'DY IS TOO LARGE FOR SOME INTERVAL OF XOUT(I),',/,
     14X,'OR XOUT(I) HAS NOT BEEN SPECIFIED IN ORDER OF INCREASING MAGNI
     1TUDE.')
      END
      SUBROUTINE PPARM(XO)
      REAL M
      DIMENSION HEAD(80)
      COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
C
C     THIS SUBROUTINE CONTROLS PRINTOUT OF INPUT PARAMETERS
      READ(5,100) (HEAD(I),I=1,80)
      WRITE(6,200)
      WRITE(6,201) (HEAD(I),I=1,80)
      WRITE(6,202) PA
      WRITE(6,203) M
      WRITE(6,204) S
      WRITE(6,205) A
      WRITE(6,206) DL
      WRITE(6,207) Q
      WRITE(6,208) E
      WRITE(6,209) SOURC
```

```
      WRITE(6,210) U2M
      WRITE(6,211)
      WRITE(6,212) H,HH,XC
  100 FORMAT(80A1)
  200 FORMAT(1H1,32X,'A MATHEMATICAL MODEL DESIGNED TO DESCRIBE THE DOWN
     1WIND',/,23X,'TRAVEL AND VERTICAL PROFILE OF PARTICULATE MATTER FRO
     2M AN ELEVATED SOURCE',//)
  201 FORMAT(20X,80A1,/)
  202 FORMAT(40X,'PA= ',F7.5,4X,'(AIR PERMEABILITY)')
  203 FORMAT(40X,'M= ',F5.2,7X,'(WIND PROFILE PARAMETER)')
  204 FORMAT(40X,'S = ',F5.3,6X,'(TOTAL SPECIFIC AREA)')
  205 FORMAT(40X,'A = ',F6.4,5X,'(VON KARMANS CONSTANT/10)')
  206 FORMAT(40X,'DL =',F6.3,5X,'(ROUGHNESS LENGTH)')
  207 FORMAT(40X,'Q =',F7.5,5X,'(TERMINAL VELOCITY)')
  208 FORMAT(40X,'E =',F7.3,5X,'(RETENTION FACTOR)')
  209 FORMAT(40X,'SOURC=',F8.2,1X,'(SOURCE STRENGTH)')
  210 FORMAT(40X,'U(2)=',F5.2,5X,'(2 METRE WIND)')
  211 FORMAT(//,49X,'H',9X,'HH',8X,'XO',/,44X,'ATMOSPHERIC  RELEASE  DOW
     1NWIND',/,48X,'LID       HEIGHT  DISTANCE')
  212 FORMAT(/,44X,3(F10.3))
      RETURN
      END
      SUBROUTINE PCONS(THETA,NY,RH,RHH,IC,ALPA,BETA,GAMA,LAMA,A11,D11)
      REAL M,LAMA,NU
      COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
      COMMON CV(100),RZ(100)
C
C     THIS SUBROUTINE CALCULATES AND SETS CONSTANTS FOR THE MATRIX
C
C     DETERMINE DELTA R
      DR = ALOG((H + DL)/DL)/FLOAT(NZ-1)
      HHR= ALOG((HH + DL)/DL)
      HK = ALOG((H + DL)/(HH + DL))
      HR = ALOG((H + DL)/DL)
      H1 = FLOAT(NZ)-HK/DR-(HHR-FLOAT(IFIX(HHR)))
      IHH= IFIX(H1 + 0.001)
      DR = HHR/FLOAT(IHH-1)
      NZ = IFIX(HR/DR + 0.5) + 1
      RH = FLOAT(NZ-1)*DR
      RHH= FLOAT(IHH-1)*DR
C
      RZ(1)=0.0
      CV(1)=0.0
      DO 1 I=2,NZ
      RZ(I)=RZ(I-1) + DR
      CV(I)=0.0
    1 CONTINUE
      CV(IHH)=1.0
```

```
C
C       NORMALIZE
        DL=DL/H
        Q=Q/(U2M*A)
        PA=PA/(U2M*A)
C
C       CONSTANTS FOR THE MATRIX
        NU=(A/DL)*(H*DL/(2. + H*DL))**(-M)
        ALPA=NU*THETA*DY/DR**2.
        BETA=NU*THETA*DY*Q/DR
        GAMA=NU*(1.-THETA)*DY/DR**2.
        LAMA=NU*(1.-THETA)*DY*Q/DR
        A11=E*(PA+Q/S )*S*NU*THETA*DY/DR
        D11=E*(PA+G/S )*S*NU*(1.-THETA)*DY/DR
C
        IF(IC-1) 2,3,3
      2 RETURN
C
C       PRINT OUT RUN PARAMETERS AND MATRIX CONSTANTS
      3 WRITE(6,200)
        WRITE(6,201) DR,NZ,DY,NY,THETA
        WRITE(6,202) H,HR,RH
        WRITE(6,203) HH,HHR,RHH,THH
        WRITE(6,204)
        WRITE(6,205) ALPA,BETA,GAMA,LAMA,A11,D11
    200 FORMAT(/,32X,'RUN PARAMETERS',//,39X,'DR',8X,'NZ',8X,'DY',8X,'NY',
       16X,'THETA')
    201 FORMAT(36X,F7.3,4X,I4,5X,F7.3,4X,I5,4X,F7.3)
    202 FORMAT(/,40X,'H',8X,'HR',8X,'RH',/,34X,F10.3,2X,F7.3,4X,F7.3)
    203 FORMAT(/,39X,'HH',7X,'HHR',7X,'RHH',7X,'THH',/,35X,F9.3,1X,F7.3,3X
       1,F7.3,3X,I5)
    204 FORMAT(/,32X,'MATRIX CONSTANTS',//,37X,'ALPHA',6X,'BETA',5X,'GAMMA
       1',6X,'LAMBA',6X,'A1',8X,'D1',/)
    205 FORMAT(34X,5F10.4)
        RETURN
        END
        SUBROUTINE  POUTP(IC,IK,K,ZZ,ID,RD,ICZX,ZX,IR,RIR,IY,YOUT,NUMOX)
        REAL M
        DIMENSION XCUT(20),STATZ(10),ENDZ(10),ZOUIN(10),ZZ(1),RZZ(25)
        DIMENSION ID(1),RD(1),ZX(1),IR(1),RIR(1),RZX(2),IY(1),YOUT(1)
        COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
        COMMON CV(100),RZ(100)
C
C       THIS SUBROUTINE SETS UP PRINTOUT CONTROLS
        READ(5,100) NUMCX,NOVES,ICZX,IK
        READ(5,101) (XOUT(I),I=1,NUMOX)
        READ(5,102) (STATZ(I),ENDZ(I),ZOUIN(I),I=1,NOVES)
C
```

```
      IF(IK) 1,1,2
    1 IK=1
    2 CONTINUE
C
C     Z OUTPUT ARRAY SET UP
      K=1
      DO 3 J=1,NCVES
      IF(K-1) 4,4,5
    5 IF(IFIX(10.*(STATZ(J)+0.005)) - IFIX(10.*(ZZ(K)+0.005))) 4,6,7
    7 K=K+1
    4 ZZ(K)=STATZ(J)
    6 DO 8 I=1,25
      K=K+1
      ZZ(K)=ZZ(K-1) + ZOUIN(J)
      IF(IFIX(10.*(ZZ(K)+0.005)) - IFIX(10.*(ZZ(K-1) + 0.005))) 9,9,10
   10 IF(IFIX(10.*(ZZ(K)+0.005)) - IFIX(10.*(ENDZ(J) + 0.005))) 8,3,3
    8 CONTINUE
      GO TO 11
    9 K=K-1
    3 CONTINUE
   11 CONTINUE
C
      L=1
      DO 12 I=1,K
      RZZ(I)=ALOG((ZZ(I)/H+DL)/DL)
      DO 13 J=L,NZ
      IF(RZZ(I)-RZ(J)) 14,15,16
   14 ID(I)=J-1
      RD(I)=(RZZ(I) - RZ(J-1))/DR
      GO TO 19
   15 ID(I)=J
      RD(I)=(RZZ(I)-RZ(J))/DR
      GO TO 19
   16 CONTINUE
   13 CONTINUE
   19 L=J
   12 CONTINUE
      DO 40 I=1,K
      ZZ(I)=ZZ(I)+0.0001
   40 CONTINUE
C
      IF(ICZX-1) 20,20,21
C
C     READ HEIGHTS FOR HORIZONTAL PROFILE AND TRANSFORM TO R,Y PLANE
   21 L=ICZX-1
      READ(5,102) (/X(I),I=1,L)
      DO 22 I=1,L
      RZX(I)=ALOG((ZX(I)/H+DL)/DL)
```

```
      DO 23 J=1,NZ
      IF(RZX(I)-RZ(J)) 25,24,23
   25 IF(RZ(J)-RZX(I)-0.5*DR) 24,24,26
   23 CONTINUE
   24 IR(I)=J
      RIR(I)=(RZ(J)-RZX(I))/DR
      GO TO 22
   26 IR(I)=J+1
      RIR(I)=(RZ(J)-RZX(I))/DR
   22 CONTINUE
C
   20 DO 30 I=1,NUMOX
      YX=ALOG(XOUT(I)/H + 1.)/DY
      IYX=IFIX(YX)
      RYX=YX-FLOAT(IYX)
      IF(RYX-0.5) 31,31,32
   31 IY(I)=IYX
      GO TO 33
   32 IY(I)=IYX + 1
   33 YOUT(I)=H*(EXP(FLOAT(IY(I))*DY) - 1.)
   30 CONTINUE
C
      IF(IC-2) 34,35,35
   34 RETURN
C
C     PRINT OUT OUTPUT CONTROLS
   35 WRITE(6,200)
      WRITE(6,201) (STATZ(I),ENDZ(I),ZOUIN(I),I=1,NOVES)
      WRITE(6,202)
      WRITE(6,203) (ZZ(I),RZZ(I),ID(I),RD(I),I=1,K)
      WRITE(6,204)
      WRITE(6,205) (XOUT(I),YOUT(I),IY(I),I=1,NUMOX)
      IF(ICZX-1) 36,36,37
C
C     PRINT OUT OUTPUT CONTROLS FOR HORIZONTAL PROFILE
   37 WRITE(6,206)
      WRITE(6,207) (ZX(I),RZX(I),IR(I),RIR(I),I=1,L)
C
  100 FORMAT(4I2)
  101 FORMAT(8F10.0)
  102 FORMAT(3F10.0)
  200 FORMAT(1H1,32X,'Z OUTPUT CONTROLS',//,33X,'A) INTERVALS',/,37X,'ST
     1ART         END      INCREMENT',/)
  201 FORMAT(37X,F6.2,3X,F6.2,4X,F6.2)
  202 FORMAT(/,33X,'B) ARRAY',/,39X,'Z              RZ          ID       THETA',
     1/)
  203 FORMAT(35X,F8.3,2X,F8.3,4X,I4,4X,F6.4)
  204 FORMAT(/,32X,'X OUTPUT',/,39X,'X          X-OUT          IY',/)
```

```
205 FORMAT(33X,F10.4,F10.4,4X,I4)
206 FORMAT(/,33X,'X VS Z OUTPUT CONTROLS',/,39X,'ZX',7X,'RZX',8X,'IR',
   16X,'THETA',/)
207 FORMAT(35X,F8.3,2X,F8.3,3X,I4,7X,F5.2)
 36 RETURN
    END
    SUBROUTINE  PTRID(J,ALPA,BETA,GAMA,LAMA,A11,D11,THETA,IC,IC1,J3)
    REAL M,LAMA
    DIMENSION XI(100),D(100),W(100),G(100),QQ(100),CG(100)
    COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
    COMMON CV(100),RZ(100)
C
C   THIS SUBROUTINE INVERTS THE MATRIX
    XI(1)=EXP((FLOAT(J)-1.+(1.-THETA))*DY)
    D(1)=(GAMA + LAMA)*CV(2) -(GAMA + D11 - 1./XI(1))*CV(1)
    K=NZ-1
C
    DO 1 I=2,K
    XI (I)=EXP(-(FLOAT(I)-1.)*(M+1.)*DR)*XI(1)
    D(I)= (GAMA + LAMA)*CV(I+1) - (2.*GAMA + LAMA -1./XI(I))*CV(I) +
   1  GAMA*CV(I-1)
  1 CONTINUE
    XI(NZ)=EXP(-(FLOAT(NZ)-1.)*(M+1.)*DR)*XI(1)
    D(NZ)= -(GAMA + LAMA*(1.      )-1./XI(NZ))*CV(NZ) + GAMA*CV(NZ-1)
C
    B= -(ALPA + BETA)
    C= - ALPA
    W(1)=ALPA + A11 + 1./XI(1)
    G(1)=D(1)/W(1)
C
    DO 2 I=2,NZ
    QQ(I-1) = B/W(I-1)
    W(I)=2.*ALPA + BETA + 1./XI(I) - C*QQ(I-1)
    IF(I-NZ) 3,4,4
  4 W(I) = W(I) - ALPA + BETA
  3 G(I)=(D(I)-C*G(I-1))/W(I)
  2 CONTINUE
C
    CV(NZ)=G(NZ)
    DO 5 I=1,K
    L=NZ-I
    CV(L)=G(L) - QQ(L)*CV(L+1)
  5 CONTINUE
    IF(IC-3) 6,7,7
  6 RETURN
C
C   INTERROGATE MATRIX
  7 IF(J3-IC1) 6,8,6
```

```
    8 J3=0
      DO 9 I=1,NZ
    9 CG(I)=ALOG(CV(I)+1.)/0.69315
      WRITE(6,100)
      WRITE(6,101) J
      WRITE(6,102)
      WRITE(6,103) (I,CV(I),CG(I),D(I),XI(I),W(I),G(I),I=1,NZ)
  100 FORMAT(1H1,52X,'VERTICAL PROFILE',/,48X,'AND MATRIX INTERROGATION'
     1)
  101 FORMAT(/,53X,'ITERATION=',I5,/)
  102 FORMAT(24X,'I',7X,'CV',4X,'LN(CV+1)/LN(2)',5X,'D',10X,'XI',11X,'W'
     1,11X,'G',/)
  103 FORMAT(22X,I3,1X,E12.5,2X,F9.6,1X,4E12.5)
      RETURN
      END
      SUBROUTINE  PMBAG(ICZX,RH,RHH,AIRM,GRDM,GRDM1,PERAR,PERGD,TOTAL,
     1  PEAK,PZ,CS,COFAC,IR,RIR,J)
      REAL M
      DIMENSION IR(2),RIR(2),CS(25)
      COMMON PA,M,S,A,DL,Q,E,SOURC,U2M,DR,DY,H,HH,NZ
      COMMON CV(100),RZ(100)
C
C     SUBROUTINE TO CALCULATE PEAKS AND MASS BALANCES
      CK1=((H*DL/(2.+H*DL))**M) DR*DL
      CK2= DY*A*E*(PA*Q/S )*S
      CK3= DL*DR*EXP(RHH*(M+1.))*((H*DL/(2.+H*DL))**M)
      COFAC=SOURC/(U2M*H*CK3)
C
C     MASS IN THE AIR
      AIRM=0.5*(CV(1) + EXP(RH*(M+1.))*CV(NZ))
      K=NZ-1
      DO 1 I=2,K
      AIRM=AIRM + EXP((FLOAT(I)-1.)*DR*(M+1.))*CV(I)
    1 CONTINUE
      AIRM=AIRM*CK1
C
C     MASS ON THE GROUND
      GRDM2=0.5*(CV(1)*EXP(FLOAT(J)*DY)*CK2)
      GRDM= (GRDM1 + GRDM2) + GRDM
      GRDM1= GRDM2
C
C     PERCENT IN AIR, AND ON THE GROUND
      PERAR=100.*AIRM/CK3
      PERGD=100.*GRDM/CK3
      TOTAL=PERAR + PERGD
C
      IF(ICZX) 2,2,3
    2 RETURN
```

```
    5 GO TO [illegible]
C
C     CALCULATE AND LOCATE PEAK CONCENTRATION
    4 PEAK=CV(1)
      DO 6 I=2,NZ
      IF(CV(I)-PEAK) 7,7,8
    8 PEAK=CV(I)
    6 CONTINUE
    7 IF(CV(1)-PEAK) 9,10,10
   10 II=1
      PZ=RZ(1)
      GO TO 11
    9 II=I-1
      D=(RZ(II-1)**2.-RZ(II)**2.)*(RZ(II)-RZ(II+1))-(RZ(II)**2. - RZ(II+
     11)**2.)*(RZ(II-1)-RZ(II))
      V=(CV(II-1)-CV(II))*(RZ(II)-RZ(II+1))-(CV(II)-CV(II+1))*(RZ(II-1)-
     1RZ(II))
      V=V/D
      B=(RZ(II-1)**2.-RZ(II)**2.)*(CV(II)-CV(II+1))-(RZ(II)**2.-RZ(II+1)
     1**2.)*(CV(II-1)-CV(II))
      B=B/D
      C=CV(II) - V*(RZ(II)**2.) - B*RZ(II)
      PZ= -B/(2.*V)
      PEAK = V*(PZ**2.) + B*PZ + C
   11 GO TO (12,5,5),ICZX
    5 L=ICZX-1
C
C     INTERPOLATE TO FIND HORIZONTAL PROFILE
      CALL BESIN(CV,NZ,IR,RIR,L,CS)
   12 CONTINUE
      RETURN
      END
      SUBROUTINE  BESIN(CG,NZ,IARRY,RARRY,N,CS)
      DIMENSION CV(100),CS(25),IARRY( 1),RARRY( 1),CG(100)
C
C     THIS SUBROUTINE APPLIES BESSEL'S INTERPOLATION FUNCTION
C     TO CALCULATE CONCENTRATION AT SPECIFIED HEIGHTS
      DO 8 I=1,NZ
    8 CV(I)=ALOG(CG(I)+1.)
      DO 9 J=1,N
      I=IARRY(J)
      TH=RARRY(J)
      B2=TH*(TH-1.)/4.
      B3=TH*(TH-0.5)*(TH-1.)/6.
      B4=(TH+1.)*TH*(TH-1.)*(TH-2.)/48.
      IF(I-NZ) 2,3,3
    3 CS(J)=CV(NZ)
      GO TO 1
```

```
      2 CS(J)=0.5*(CV(I) + CV(I+1)) + (TH-0.5)*(CV(I+1)-CV(I))
        IF(I-1) 1,1,4
      4 IF(I-(NZ-1)) 5,1,1
      5 CS(J)=CS(J) + B2*(CV(I+2)-CV(I+1)-CV(I)+CV(I-1)) + B3*(CV(I+2)-
       1 3.*CV(I+1) + 3.*CV(I) - CV(I-1))
        IF(I-2) 1,1,6
      6 IF(I-(NZ-2)) 7,1,1
      7 CS(J)=CS(J) + B4*(CV(I+3)-3.*CV(I+2)+2.*CV(I+1)+2.*CV(I)-3.*CV(I-1
       1) + CV(I-2))
      1 CONTINUE
        CS(J)=EXP(CS(J))-1.
        IF(CS(J)) 10,9,9
     10 CS(J)=0.0
      9 CONTINUE
        RETURN
        END
        SUBROUTINE PBALC(ICZX,I2,PEAK,PZ,CS J,DY,PERAR,PERGD,TOTAL,COFAC,
       1 ZX,BO)
        DIMENSION BO(25,7),CS(25),ZX(2)
C
C       THIS SUBROUTINE CONTROLS OUTPUT OF PEAKS AND IASS BALANCES
C       AND HORIZONTAL PROFILES
        GO TC (1,1,2),ICZX
      1 BO(I2,1)=PEAK
        BO(I2,3)=PZ
        GO TO (3,4,2),ICZX
      3 BO(I2,2)=0.0
        GO TC 5
      4 BO(I2,2)=CS(1)
        GO TO 5
      2 BO(I2,1)=CS(1)
        BO(I2,2)=CS(2)
        BO(I2,3)=0.0
      5 BO(I2,4)=FLOAT(J)*DY
        BO(I2,5)=PERAR
        BO(I2,6)=PERGD
        BO(I2,7)=TCTAL
        IF(I2-25) 5,7,7
      7 WRITE(6,200) COFAC
        GO TO (8,8,9),ICZX
      9 WRITE(6,201)
        GO TC (10,11,9),ICZX
     11 WRITE(6,202) ZX(1)
        GO TO 10
      9 WRITE(6,203) ZX(1),ZX(2)
     10 WRITE(6,204)
        WRITE(6,205) ((BO(I,K),K=1,7),I=1,I2)
        I2=0
```

```
    6 CONTINUE
  200 FORMAT(1H1,42X,'NORMALIZING FACTOR C(O)=',F9.4)
  201 FORMAT(43X,'PEAK C(I) GIVEN IN COL. 1')
  202 FORMAT(43X,'C(J) AT Z=',F7.3,'IN COL. 2')
  203 FORMAT(43X,'C(J) AT Z=',F7.3,'IN COL. 1',/,43X,'C(J) AT Z=',F7.3,
     1'IN COL. 2')
  204 FORMAT(/,27X,'C(1)/C(O) C(2)/C(O)  PEAK RZ',7X,'Y',4X,'MASS IN   M
     1ASS ON    TOTAL',/,68X,'AIR      GROUND',/)
  205 FORMAT(25X,F10.6,F10.6,2X,F7.3,1X,F9.4,2X,F6.2,4X,F6.2,4X,F6.2)
      RETURN
      END
C
C
C     MODIFIED DEC 12/76
C
C
      SUBROUTINE PPOUT(J1,J2,DOSE,ZZ,INN,YOUT,PERA,PERG,TOT,CD)
C
C     OUTPUT SUBROUTINE FOR MAIN RESULTS
      DIMENSION YOUT(1),ZZ(1),DOSE(25,4),PERA(1),PERG(1),TOT(1)
      DIMENSION  CD(1),GAUSS(20),PDOSE(25,20),PCD(20)
      K1=J2-J1+1
      K2=J2
C
C
C     CALCULATE LATERAL DISPERSION FUNCTION
C
C     YC IS CROSSWIND COORDINATE
C     IPSC IS 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F
C
      IF (J2 - 4) 41,40,41
   40 READ(5,109)YC,IPSC
      WRITE(6,111)YC
      WRITE(6,112)IPSC
      WRITE(6,113)
   41 CONTINUE
      DO 60 I=K1,K2
      SIGF = 1.0/(1.0+0.0001*YOUT(I))**0.5
      GO TO (51,52,53,54)IPSC
   51 SIGY = 0.11*YOUT(I)*SIGF
      GO TO 55
   52 SIGY = 0.08*YOUT(I)*SIGF
      GO TO 55
   53 SIGY = 0.06*YOUT(I)*SIGF
      GO TO 55
   54 SIGY = 0.04*YOUT(I)*SIGF
   55 PI = 3.14159265358979323846264
   60 GAUSS(I) =EXP(-YC**2/(2.*SIGY**2))/(SQRT(2.0*PI)*SIGY)
```

```
      WRITE(6,101)
      WRITE(6,102) (YCUT(I),I=K1,K2)
      WRITE(6,103)
      DO 4 I=1,INN
C     APPLY LATERAL DISPERSION FUNCTION
      DO 3 J=K1,K2
      K3 = J-K1+1
    3 PDOSE(I,J)=DOSE(I,K3)*GAUSS(J)
      WRITE(6,104) ZZ(I),(PDOSE(I,J),J=K1,K2)
    4 CONTINUE
      WRITE(6,105)  (PERA(I),I=K1,K2)
      WRITE(6,106)  (PERG(I),I=K1,K2)
      WRITE(6,107) (TOT(I),I=K1,K2)
C     APPLY LATERAL DISPERSION FUNCTION
      DO 5 I = K1,K2
      K3 = I-K1+1
    5 PCD(I)=CD(K3)*GAUSS(I)
      WRITE(6,108)(PCD(I),I=K1,K2)
      WRITE(6,110)(GAUSS(I),I=K1,K2)
  101 FORMAT(1H1,48X,'DOWNWIND CONCENTRATIONS')
  102 FORMAT(//,11X,4(22X,'X'),//,13X,4(14X,F9.2))
  103 FORMAT(/,4X,'VERTICAL GRID',4(10X,'CONCENTRATION'),/,9X,'Z(I)')
  104 FORMAT(7X,F6.2,2X,4(10X,F13.6))
  105 FORMAT(/,6X,'MASS IN AIR',8X,F13.6,3(10X,F13.6))
  106 FORMAT(/,3X,'MASS ON GROUND',8X,F13.6,3(10X,F13.6))
  107 FORMAT(/,8X,'TOTAL',2X,4(10X,F13.6))
  108 FORMAT(/,3X,'DEPOSIT DENSITY',7X,F13.6,3(10X,F13.6))
  109 FORMAT(F10.0,I3)
  110 FORMAT(/,3X,'CROSSWIND FUNCTION',4X,F13.6,3(10X,F13.6))
  111 FORMAT(//,40X,'YC =',F7.1,3X,'(CROSSWIND COORDINATE)')
  112 FORMAT(40X,'IPSC =',I3,5X,'(STABILITY CATEGORY INDICATOR)')
  113 FORMAT(40X,'IPSC = 1,2,3,4 FOR STABILITY CATEGORIES C,D,E,F.')
      RETURN
      END
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13. ABSTRACT

A mathematical model for estimating concentrations and ground deposit densities from a low level point source of particulates up to 20 μm in diameter has been developed. The model applies K theory to account for vertical dispersion and Gaussian spread to account for lateral dispersion. Results for the limiting case of zero terminal velocity with negligible retention at the ground are compared directly to field experimental data for a source near ground level and to establish Gaussian dispersion from an elevated source. The vertical dispersion function and lower boundary condition for an existing line source model were applied in the present point source model. Previous comparison to ground deposit densities measured in various field experiments indicate that estimates from the line source model are reasonable, although further experiments would be useful.

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